Volume 6 September, 1927 Number 9

JOURNAL

OF THE

AMERICAN WELDING SOCIETY

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33 West Thirty-ninth Street, New York

American Welding Society

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AMERICAN WELDING SOCIETY
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JOURNAL

Volume 6 SEPTEMEBR, 1927 Number 9

PROGRAM
of
1927 FALL MEETING
AMERICAN WELDING SOCIETY
to be held in
DETROIT

SEPTEMBER 19, 20, 21, 22 and 23, 1927

BOOK-CADILLAC HOTEL

EXPOSITION AT CONVENTION HALL
Cass and Woodward Avenues

All Sessions Start Promptly as Scheduled

IMPORTANT NOTICE

Members and their guests are requested to register as admission to Convention Hall and to most of the social events will be by badge only.

MONDAY, SEPTEMBER 19

Morning

Registration—Registration facilities will be provided for members and guests at the Book-Cadillac Hotel commencing Monday at 9:00 a. m. A registration fee of $1.00 per person will be charged.

Afternoon

Meeting of Board of Directors, A. W. S.—2:00 p. m., Book-Cadillac Hotel.

Evening

Meeting of American Bureau of Welding and Pressure Vessel Research Committee—7:30 p. m., Book-Cadillac Hotel.

TUESDAY, SEPTEMBER 20

Morning

Technical Session—10:00 a. m., Book-Cadillac Hotel. S. W. Miller presiding.

1. Welding the Aircraft Structure by J. B. Johnson, Chief Material Branch, War Department, Air Corps, McCook Field.

2. Welding in Aircraft Construction, Mr. Maylor, Chief Engineer, Stimson Aircraft Company.

3. The Bend Test as Applied to Welded Coupons by W. B. Miller, Union Carbide & Carbon Research Laboratories.

Afternoon

Technical Session—2:00 p. m., Book-Cadillac Hotel. H. L. Whittemore presiding.

1. Report of San Francisco Section's Investigations on "Study of Welds Subjected to High Temperatures."

2. Heat Treatment by the Oxy-Acetylene Flame by E. E. Thum, Associate Editor, Iron Age.

3. A Metallurgical Study of Welds by G. R. Brophy, Research Laboratory, General Electric Company.

Evening

Theatre Party—Details will be announced later. Admission by ticket only, secured when you register.

WEDNESDAY, SEPTEMBER 21

Morning

Technical Session—10:00 a. m., Book-Cadillac Hotel. A. E. Gaynor presiding.

1. The Use of Welding in Car Construction by Victor Willoughby, General Mechanical Engineer, American Car and Foundry Company.

2. Automobile Welding by W. C. Happ, Chief Engineer, Dept. Methods and Standards, Studebaker Corporation.

It is planned to have a number of automobile concerns discuss this paper.

Afternoon

Inspection Tours—2:00 p. m.

Arrangements have been made for inspection tours to the River Rouge Plant of the Ford Motor Company and to the Ford Airport.

Evening

Meeting of Structural Steel Welding Research Committee—7:30 p. m., Book-Cadillac Hotel.

Grand Arabian Ball with American Society for Steel Treating, Hotel Statler.

One of the high lights of the Convention will be the Grand Arabian Ball in the Ball Room of the Statler on Wednesday evening at 10:00 o'clock. The room will be transformed into a beautiful Arabian scene. Jean Goldkette's Kentucky Colonels will provide the lively tempo.

Watch for special features of this ball and do not fail to attend. It is arranged exclusively in honor of the members of the four national societies and the exhibitors. Admission by ticket only, secured when you register.

THURSDAY, SEPTEMBER 22

Morning

Technical Session—10:00 a. m., Book-Cadillac Hotel. W. C. Sprau presiding.

1. Study of Oxy-Acetylene Welding as Applied to Light Gauge Pressure Containers by H. J. Grow, Air Reduction Sales Company.
2. Welding in the Design of Steel Plate Work by L. J. Sforzini, Engineering and Maintenance Department, Eastman Kodak Company.

Afternoon

Technical Session—2:00 p. m., Book-Cadillac Hotel. F. T. Llewellyn presiding.

1. Arc Welding in Buildings by Joseph Matte, Jr., of Albert Kahn, Inc.
2. A Recent Addition to the List of Arc Welded Buildings by G. H. Danforth, Contracting Engineer, Fabricating Section, Jones & Laughlin Steel Corp.

Evening

Annual Fall Dinner Dance of the American Welding Society, 6:30 p. m., Book-Cadillac Hotel. F. M. Farmer presiding.

EXPOSITION

Welding and Cutting Exposition Largest Ever Held

The Welding and Cutting Exposition held under the auspices of the American Welding Society and in cooperation with the National Steel and Machine Tool Exposition in Detroit the week of September 19 will be the largest exhibit of its kind ever held. A special section of Convention Hall of over 10,000 square feet has been set aside for the welding exhibit. Consequently all of the exhibits will be grouped together and the thousands in attendance will have the opportunity to observe the latest and best equipment and developments in this line.

Entertainment for the Ladies

MONDAY

September 19, 1927

Luncheon at Statler Hotel, 12:30 p. m., followed by an automobile trip.

TUESDAY

September 20, 1927

Shopping Tour or Bridge Party, 2:00 p. m.

Theatre Party, evening. Details will be announced later.

WEDNESDAY

September 21, 1927

Luncheon and Musicale at the Detroit Yacht Club.

Grand Arabian Ball with A. S. S. T., evening, Hotel Statler.

THURSDAY

September 22, 1927

Theatre Party at Bonstelle Theatre, 2:00 p. m.

Annual Fall Dinner Dance, A. W. S., 6:30 p. m., Book-Cadillac Hotel.

Annual Fall Dinner

American Welding Society

The Outstanding Social Event of the Fall Meeting

No Tiresome Speeches

The Price Has Been Reduced to Five Dollars

Special Entertainment

Bring the Ladies

Plenty of Dancing

Good Food

Make Reservations for Tickets Now

Thursday, Sept. 22nd

FALL MEETING

This year the Fall Meeting will be the greatest meeting in the history of the society. A large number of important technical sessions have been planned, which is to be supplemented by the largest welding exposition ever held in the world.

Entertainment features assure a good time for all those who will attend. Four national societies will hold their meeting in Detroit at the same time. The American Welding Society must have the support of the entire welding industry in order that it may occupy its proper place as a going national organization.

The large companies identified with the society are particularly requested to cooperate by sending a large delegation to the technical sessions and to the annual fall dinner of the society. For the first time the society will have the benefit of a reduced fare, which should prove particularly attractive to the members in bringing their wives and daughters.

Reservations for the dinner should be made at once in order that suitable facilities may be provided.

REDUCED RAILROAD RATES

Members of the A. S. S. T., A. W. S., and I. of M., have been granted reduced fare rates for the Detroit Convention. The railroads have agreed to sell round trip tickets at fare and one-half on the identification certificate plan.

The identification certificates will be mailed to the members of these societies direct from each of the society headquarters.

Please note that tickets purchased with identification certificates will not be accepted on extra fare trains. Tickets may be purchased going from September 15th to 21st (inclusive) with final return limit to original starting point, not later than midnight, September 29.

Any member having round trip ticket to Detroit reading via Buffalo or Cleveland may, if he so chooses, use the boats of the D. & C. line. The D. & C. Navigation Company will accept, on their steamers for transportation, going or returning, that portion of your railroad ticket calling for transportation from either Buffalo or Cleveland to Detroit.

DAILY NEWSPAPER

The *Daily Metal Trade*, published in Cleveland by the Penton Publishing Company, will issue a special edition during four days of the convention, with 8 pages devoted exclusively to the activities of the exposition and convention. This will have a circulation among the hotels and at the exposition. Watch for it!

Golf Tournament—Fall Meeting

A committee, composed of J. M. Watson, Detroit, chairman; A. O. Fulton, Boston, and W. C. Bell, Cleveland, as members, are in charge of the golf tournament, which will be held on one of Detroit's splendid golf courses.

Prizes

The Firth Sterling Steel Co., International Nickel Co., McGill Metal Co., and General Alloys Co. have all donated for prizes a set of stainless clubs, consisting of midiron, mashie, niblick and putter. In addition to the club sets, numerous other prizes will be awarded.

The following rules govern:

1. Any participant may play in the tournament either Tuesday, Wednesday or Thursday, but the first round on the course any of these days constitutes the tournament score.
2. Each participant will be given a handicap by the tournament committee. This will be based on his State handicap card (if he has one); his club handicap or the average of his best 5 scores for 18 holes made this year. In addition he will be required to give the name of his home course, its par and total yardage. No handicap will be given exceeding 30.
3. U. S. G. A. rules to apply, except where qualified by local rules of the club where the tournament is played.
4. Gross and net prizes to be equally divided, that is, first, second, third, etc., gross; first, second, third, etc., net.
5. The prizes will be listed by the committee in the order of their importance. No player shall be eligible for more than one prize. In case any player wins more than one prize he will be awarded only that one which is highest on the list.
6. While guests may participate in the tournament, no prizes will be awarded, except to members of the four convening societies and exhibitors.

BRING YOUR MEMBERSHIP CARD

FALL MEETING

(News release by the American Society for Steel Treating)

Meetings of the four technical bodies, to be held in Detroit, September 19 to 23 concurrently, with the Ninth Annual National Steel and Machine Tool Exposition, will not be "all work and no play."

Although a heavy program of technical papers is provided for the meetings that will be held each morning and afternoon, the convention will have their lighter side with banquets, balls, and a golf tournament as outstanding features.

The American Society for Steel Treating, which will hold its annual technical sessions in Hotel Statler, plans a ball in the same hotel on Wednesday night, September 21. Part of the fall meeting of the Institute of Metals in Book-Cadillac Hotel will be the institute's annual dinner on the same night. The American Welding Society, which holds its annual meeting in the Book-Cadillac Hotel, plans a banquet and ball for Thursday night, September 22. The Production Meeting of the Society of Automotive Engineers probably will include a similar social function in its Hotel Statler headquarters.

The golf tournament will be open to all members of the four organizations. Arrangements are in the hands of a committee headed by J. M. Watson of Detroit, and including A. O. Fulton of Boston and W. C. Bell of Cleveland. Complete rules and regulations have not yet been announced. But the committee has announced that each contestant must present a satisfactory certificate setting forth his handicap, with a maximum of 30 allowed; and also that contestants may play Tuesday, Wednesday and Thursday of exposition week, but the first round any of these days will constitute that player's tournament score.

The Ninth Annual National Steel and Machine Tool Exposition in Convention Hall, Detroit, the largest collection of industrial nature ever assembled, will open at noon daily from Monday, September 19, through Friday, September 23. From noon until 2 p. m. daily will be a special executive period and will be reserved to holders of special executives' invitations.

On Monday, Wednesday and Friday nights of exposition week, the hall will be open until 10 p. m., while on Tuesday and Thursday nights, it will close at 6 p. m.

Observance of the week of Sept. 19 as National Metal Week has received the hearty backing of members and officers of the four technical societies that will meet in Detroit that week, concurrently with the Ninth Annual National Steel and Machine Tool Exposition. In fact, everyone agrees that some national recognition be given both in the metal industries and by the general public, to the unusual gathering of metal experts expected to take place in Detroit, and of its tremendous possible influence on billions of dollars' worth of industrial production. They point out that the country at large should be made conscious of the exchange of ideas and technical information that will take place in Detroit during National Metal Week, when these four important technical groups hear papers read covering the latest developments produced by metal experts all over the world.

TRAINING COURSES

The first of a series of training courses for welders and others interested appeared as a supplement in the June issue with the publication of the Training Course for Thermit Welders. This course is also available in bulletin form at fifty cents per copy with special prices in quantity lots of fifty or more.

The Training Course for Resistance Welders is published in this issue. It is also available in separate form at thirty-five cents per copy and special prices for quantity lots.

Orders may also be placed for the Gas and Electric Arc Courses, which will appear in subsequent issues.

TECHNICAL CRYSTALLIZATION

(*Taken from July 28, 1927, issue Engineering News-Record*)

Technical societies have grown remarkably in recent years. Even at first glance at this growth one may recognize that there is in progress not a chance movement, but a transformation resulting from definite and significant forces. All groups of technical men are growing more rapidly than the profession itself. General engineering societies share this growth with the various specialized organizations. Plainly, a crystallization is going on in the technical field, an agglomeration of individuals into larger and more powerful units.

What does this movement signify? A spontaneous drift of the individuals, in the main uninfluenced by propaganda or solicitation, it arises obviously from a conviction that strength lies in union. But if we ask why the

engineer should seek for a stronger position in the world, we face a more fundamental question. The development of human affairs tends to involve him in an ever broader range of activities and relations. Thereby he finds himself confronted by changing conditions and increased difficulties—conditions and difficulties quite different from those known to his professional predecessors. As these difficulties become more complex and formidable, he finds ultimately his own judgment and conscience, guided only by the precedent set in the past, insufficient to deal with them. In this conjuncture he is bound to seek the help of his fellows, and he finds the sought-for cooperative strength in the technical society.

If this is the true interpretation of the current society growth, it is a matter for serious and sober consideration by those organizations. They are not merely gaining members, they are gaining new responsibilities and new functions. Their entire relationship to their constituency is coming to be of new kind. The very fact of professional crystallization means a transfer of function: the individual turns over his problems and obligations to his group, and tacitly asks that it deal with them in his stead. Accordingly, unless the organization takes up the new functions it is in peril of failure.

The responsibility of class representation has hitherto rested lightly on technical societies, so lightly that most of them preferred to ignore it. Accordingly, they are little prepared now to admit the responsibility or act upon it. In the main they lack not only machinery and plan but even the courage to function as representative groups. But if the new responsibilities are growing from day to day, they cannot long be evaded with impunity.

For the society, then, the present is more than a time of growth, it is one of transformation. New and greatly enlarged requirements impose themselves upon the organization and the latter is bound to reshape its activities accordingly. The concepts and purposes of group activity which grow out of the changing conditions of professional life are not as yet fully definite, but they are slowly taking form. That they may be duly taken into account in realigning society functioning, there is need for broadest sympathy and keenest vision in the society councils.

STEEL DRUM WITH WELDED SEAMS WITHSTANDS HEAVY PRESSURE

(Taken from July 28, 1927, issue Engineering News-Record)

A steel drum having all seams arc-welded was subjected to a pressure of 3000 lb. per sq. in. without failure at a recent demonstration at the Sharon, Pa., plant of the Petroleum Iron Works Co. and its associate, the Penstock Construction Co.

The test was one of several made in the presence of about thirty engineers representing various industries who were interested in the results of the research and progress made with electro-metallic arc welding.

Several containers, completely welded by this method, were subjected to destructive pressures. In every case where a fracture occurred, it was in the plate at some distance away from the weld. One of the containers, 3 ft. in diameter and 2 ft. 6 in. in length, with dished heads and a one-piece shell, all of ¾-in. plate, was subjected to successive hydraulic pressures of 1500, 2500 and 3000 lb. per sq. in. without showing a trace of moisture at any of the joints. At 3090 lb. per sq. in. the hydraulic connection blew out and the test to destruction was not made. However, the container had lengthened 5¾ in. and increased almost 14 in. around the circumference midway between the heads. The computed bursting pressure was 2100 lb. per sq. in. and the tensile strength for the steel was figured at 50,000 lb. per sq. in. The internal pressure of 3090 lb. per sq. in. reached in the test corresponds to a tensile strength of 73,500 lb. per sq. in. in the shell.

MR. TOLEIK MAKES NEW CONNECTION

Mr. John A. Toleik has severed a seventeen year connection with the American Can Company to accept the position of Chief Engineer of the Gibb Welding Machines Company, Bay City, Mich.

Mr. Toleik has been in charge of all welding developments with the American Can Company and was personally responsible for the high production turned out in their many welding operations.

Mr. Toleik's chief interest with the Gibb Welding Machines Company will be in the further development of their Research Department.

SECTION ACTIVITIES

Chicago

A tentative program for the coming year is given below. This program includes moving pictures at each meeting, starting at 7.30 and continuing from forty to sixty minutes. The speaker of the evening immediately follows these pictures after being introduced by the chairman. Ample opportunity is to be provided for discussion.

Program Chicago Section—American Welding Society, 1927-1928

Sept. 16, 1927

Two reels entitled "White Coal," from the Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.
Speaker—H. H. Moss of the Linde Air Products Company.
Subject—"Pressure Piping."

Oct. 7, 1927

Two reels entitled "Electrified Travelogue," from the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
Speaker—C. J. Holslag, Electric Arc Cutting & Welding Co.
Subject — "Structural Welding," illustrated by lantern slides.

Nov. 4, 1927

Two reels entitled "Story of Steel," from U. S. Steel Corporation, New York, N. Y.
Speaker E. E. LeVan of the Linde Air Products Company.
Subject—"Stellite."

Dec. 2, 1927

Two additional reels entitled "Story of Steel," from U. S. Steel Corporation, New York, N. Y.
Speaker—J. S. Green, Chicago Steel & Wire Company.
Subject—To be determined later (including moving pictures).

Jan. 6, 1928

Last two reels entitled "Story of Steel," from U. S. Steel Corporation, New York, N. Y.
Speaker—From Page Steel & Wire Company.
Subject—To be determined later.

Feb. 3, 1928

Film No. 40 entitled "Panama Canal," one reel, from General Electric Co., Schenectady, N. Y.; also film No. 48, entitled "Making Mazda Lamps," one reel.
Speaker—From Air Reduction Company.
Subject—To be determined later.

March 2, 1928

Film No. 27, entitled "Queen of the Waves," two reels, from General Electric Co., Schenectady, N. Y.
Speaker—R. D. Malm, Chicago Manager, Lincoln Electric Co.
Subject—To be determined later.

April 6, 1928

Film No. 25, entitled "Cuba, the Island of Sugar," two reels, from General Electric Co., Schenectady, N. Y.
Speaker—From Air Reduction Company.
Subject—To be determined later.

May 4, 1928

Film No. 17, entitled "King of the Rails," three reels, from General Electric Co., Schenectady, N. Y.
Speaker—To be determined later.
Subject—To be determined later.

Considerable discussion has taken place by directors at several meetings in regard to the possibility of holding popular dinner meetings immediately preceding the technical session. It was also suggested that the section program be printed and distributed widely and several attempts be made to interest prospective members.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-62. Oxy-acetylene and Electric Welder desires position. Have had several years' experience with the following companies: Black & Knauls Pump Works, Cambridge, Mass.; U. S. Electric Welding Co., East Boston, Mass.; Mack International Truck, Long Island; Biflex Spring Company, 150 Longfellow Avenue, Bronx; Crescent Mach. Co., New Rochelle, N. Y.

A-63. Electric Welder desires position. Have had ten years' experience, including four in Marine and Ship Yard, two years in tank work, three years in auto and job shop and one year in locomotive repair. Can furnish reference.

The Use of Welding in Car Construction*

By V. R. Willoughby†

To one closely in touch with or intensely interested in the art of welding it may seem strange that welding is not being more generally used in the construction of railroad cars. He may wonder why we do not build what may be called an "all-welded" car, that is, a car wherein most if not all of the connections now secured by rivets are replaced by welding.

At the same time the question naturally arises whether it be a matter of technical difficulties, economic factors, or perhaps a conservatism on the part of those who build and use railroad cars, or again, whether it may be a lack of appreciation of the great possibilities and advantages attainable by the substitution of welding for riveted constructions in car structures.

In order to better visualize the viewpoint of the railroad men regarding the use of welded constructions in cars, let us consider the rules and regulations now in force pertaining to the welding of car parts, and let us also consider the reasons for the establishment of those rules.

Probably the world's greatest authorized representative of railroads with respect to engineering matters pertaining to plant equipment, rolling stock and motive power, is the Mechanical Section of the American Railway Association, commonly spoken of as the A. R. A. This body of men is composed of representatives of practically every railroad in the United States, Canada, Mexico and Cuba. Most of you are undoubtedly acquainted with the work of this organization. The A. R. A., on the basis of the findings of its various committees and the results of letter ballots, regulates or legislates to a very great extent what may or may not be done in matters pertaining to the design and construction of railroad transportation equipment.

This association's personnel is composed entirely of men who have had years of experience in the railroad industry and the members of all of its committees are men who are outstanding in the field pertaining to the work of that committee. At this time it would be well to emphasize that the findings of these committees are not arbitrarily arrived at. In many cases a committee assigned to investigate a given problem inaugurates an intensive research program. For example, at the present time extensive tests are being conducted at Purdue University on draft gears and also air brake equipment.

From this very brief reference to the work of the A. R. A. you can readily understand that it is not an arbitrarily functioning body, but an organization of serious minded men upon whose shoulders rests to a very great extent the safety of the railroad

* To be presented before annual fall meeting, A. W. S., September 21, 1927.
† General mechanical engineer, American Car & Foundry Company.

traveling public of this continent. The attitude of the body seems to be, as gathered from reading their discussions, "Safety First, and Never Sacrifice the Factor of Safety in Order to Attain a Lower Cost."

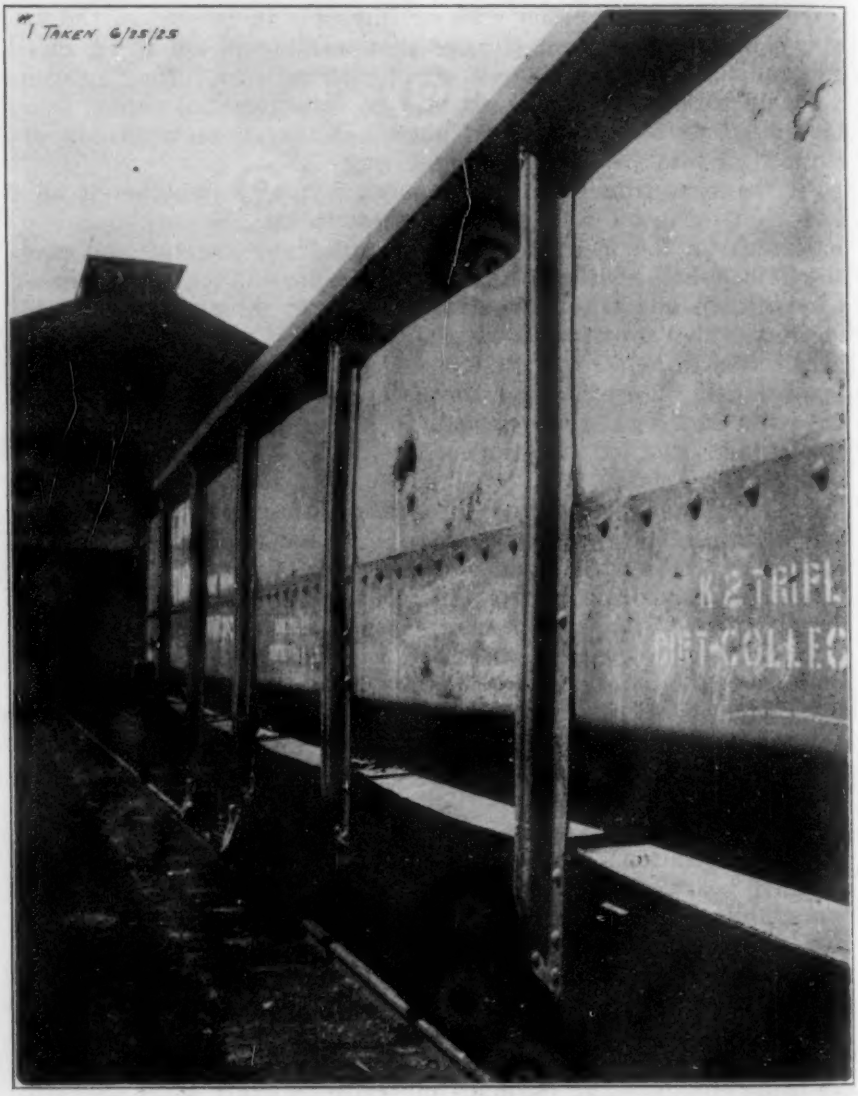

Fig. 1. Side view of spot welded car

It is indeed fortunate that we have such a body as the A. R. A. which proceeds slowly and cautiously and thoroughly investigates and submits to the acid test any radical change before permitting its use in the construction of railroad equipment, thus doing its utmost to safeguard the lives of our traveling public.

To ascertain their attitude toward welding in car construction let us turn to their "Code of Rules Governing the Condition of and Repairs to Freight and Passenger Cars for the Interchange of Traffic."

Quoting from these rules, effective Jan. 1, 1927, we have Rule No. 23, which in part reads as follows:

"Side sills may also be welded by the autogenous process, making the thickness of the metal through weld one and a half times the thickness of the metal in the sill.

"Welding cracks or fractures will not be permitted on the following:

Axles,
Arch bars,
Car wheels or tires,
Grab irons
Truck equalizers,
Sill steps,
Spring or bolster hangers,
Brake staffs,
Brake wheels,
Coupler bodies, knuckles, knuckle pins, locks, lifters and throwers.
Tanks of tank cars.
Parts made of alloy steel or heat treated carbon steel.
Top chord angles of open top all steel cars if the fracture is located at a point between bolsters more than 5 ft. from the center line of either body bolster.

"Building up worn surfaces will be permissible on the following:

Parts subject to compression only.
Spring or bolster hangers (provided that the material remaining in part is equal to at least 80 per cent of the original section).
Holes in levers (same condition as applies to spring or bolster hangers).
Center plates, truck sides, bolsters and column castings provided that the material remaining in part is equal to 60 per cent of the original section.
Coupler bodies, knuckles, locks, lifters and throwers.

"The building up of worn surfaces on car wheels is prohibited.

"Welding cracks or fractures will be permitted on the following:

Car and roof sheets.
Cast steel truck sides.
Pressed and structural steel truck sides.
Bolsters and transoms.
Brake beams.
Cast steel bolsters.
Cast steel coupler yokes.

"All of the above items except the first, welding is permitted only

when the area of the crack is less than two-fifths or 40 per cent of the total area through the section of point of fracture, but it is not permissible to weld any crack located within 6 in. of an old weld."

This Rule No. 23 also includes various regulations governing welding as regards the manner and preparation of the piece for weldings and prescribes the annealing of certain welded parts. This rule refers primarily to repair work, but, of course, we feel is equally applicable to new work in so far as the use of welding is concerned.

The object of setting forth Rule No. 23, as quoted above, is to convey an idea of the general attitude of the A. R. A. toward welding. There is nothing stated in the Rules of the A. R. A. which

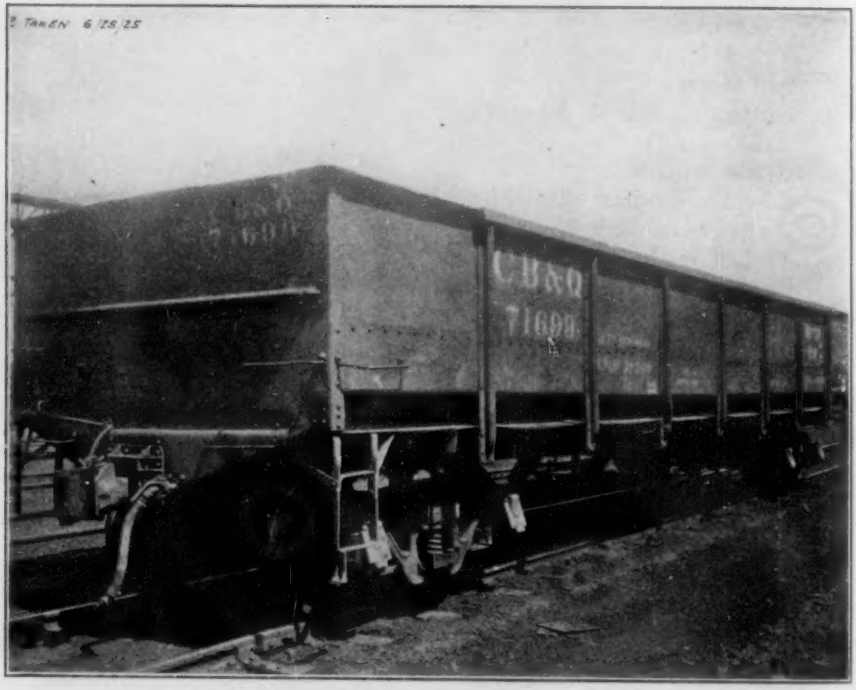

Fig. 2. Side stakes riveted to side sheet

prohibits the substitution of welded joints for riveted fastenings, except in the case of the application of safety appliances such as steps, grab irons, brake equipment and so forth, and in the case of the construction of tank cars, which latter are required to be of riveted construction throughout.

Forge or hammer welded tanks are permitted and used on the railroads. These tanks are known as Class V and their constructional details have been for some years definitely laid down by the A. R. A. Tank Car Committee's specifications, the substance of

which have within the last few months been incorporated by the Interstate Commerce Commission as a part of their regulations.

Recognition, however, has been made of the autogenous welding methods by the Tank Car Committee in that their specification carries an exception reading as follows: "Exception—Welding tanks with seams welded by such welding process as may be approved by the A. R. A. may be experimentally used in transportation service." To do even this, however, permission must be secured from both the A. R. A. Tank Car Committee and the Bureau of Explosives, and such a car may be placed in experimental service only, and must be stencilled accordingly.

It may appear strange that both the A. R. A. and the Bureau of Explosives discriminate between hammer or forge welding and gas or electric arc welding, permitting the former in the case of Class V tanks, while prohibiting gas or electric arc welding, Their stand, we believe, is well taken, however, when we consider the difference between the two welding methods and also the service in which Class V tanks are used.

In hammer welding only low carbon steel is used. The plates to be welded are cleaned of mill scale. The two edges to be welded together are lapped over each other and then placed in a specially designed furnace. The heating fuel used is water gas, the excess hydrogen of the fuel effectively preventing oxidation on the surface of the metal heated. In some cases the heating is only localized at the portion which is to be welded. When the plates have reached the welding temperature they are hammered or rolled, thus completing the weld. The surfaces to be welded are not exposed directly to the air after they have been heated and no flux is used. After the welding has been completed the tanks are annealed.

This welding process is a true welding process and after the operation has been completed we have a homogeneous weld, the metal at the weld being of exactly the same composition and structure, chemically and physically, as the parent metal. That is, the two parent metals have simply been flowed into one another as in fusing two pieces of glass.

In gas or electric arc welding the process is as you know entirely different. In this case the pieces to be joined are heated to the melting temperature and molten metal is added to fill the gap. In order to rapidly attain the melting temperature and to reduce the amount of oxidation, flux is used. This type of welding is really a recasting process and strictly speaking is not welding. The definition of welding according to the Standard dictionary is:

(1) To unite, as heated metal, in one mass, under a hammer or by pressure.

(2) To make into one strong homogeneous whole.

The gas or electric arc method of welding does not conform to either of these two definitions. The metal joined is melted, not simply heated. No pressure or hammering is involved. The re-

sult of the process is not a homogeneous whole as the weld in all cases is chemically and physically different from the parent metal.

Now the Class V tanks used on the railroads are for the transportation of liquid products such as chlorine, sulphur dioxide, anhydrous ammonia, propane and so forth. The properties of these commodities are such as to involve danger or loss of life in the event of leakage or rupture of the tank.

It is a well-known fact that when a body of metal lacks homogeneity, chemically or physically, or both, electrolytic action is readily set up resulting in what is commonly called corrosion. Chlorine and sulphur dioxide particularly are very active chemically and will quickly set up electrolytic action if given the least opportunity. It has been observed that when chlorine is stored in gas or arc welded tanks the metal immediately adjacent to the weld or in the weld is rapidly eaten away. Then, again, especially in connection with chlorine, the slag or scale which is always to some degree present in the autogenous weld is very actively attacked by the chlorine, making the welded joint porous.

Those favoring gas or electric arc welding in the construction of such tanks may claim that with the proper care taken and with an experienced welder, or by the use of the proper automatic welding apparatus, there will result a perfect weld, wholly homogeneous with the parent metal. It must be admitted that this degree of perfection may be very closely approached when the work is being conducted on a laboratory or research basis, but even under such conditions there is always a readily detectable difference between the metal in the weld and the parent metal.

Until we have reached the point where a gas or electric arc weld of steel can be obtained without the use of flux, without oxidation taking place, without affecting the carbon content of the steel, and without changing the physical structure of the steel, it will be unwise to use gas or electric arc welding in the construction of Class V tanks, which tanks are high pressure tanks for the transportation of chemically active substances.

This, as we understand the problem, is the basis of the opposition against the request now being made to the Bureau of Explosives of the Interstate Commerce Commission to permit the use of arc and gas welded Class V tanks.

In view of the fact that the railroads seem to be free to substitute welding for riveting in the construction of freight and passenger cars, it may be wondered why but little appreciable progress has been made in this direction. There are several answers to this question, any one of which presents a major problem in itself.

They are not as familiar with welding as they are with riveting. They know what a riveted joint will do but they are not sure how a welded joint will stand up. They realize that in welding the quality of a weld depends to a very large extent upon the welder. Thus we have the human element entering into the making of a weld, and the human element is not always dependable. Furthermore,

it is practically impossible in many cases to detect an inferior weld by inspection, while it is a simple matter to test a rivet for tightness without in any way injuring its strength.

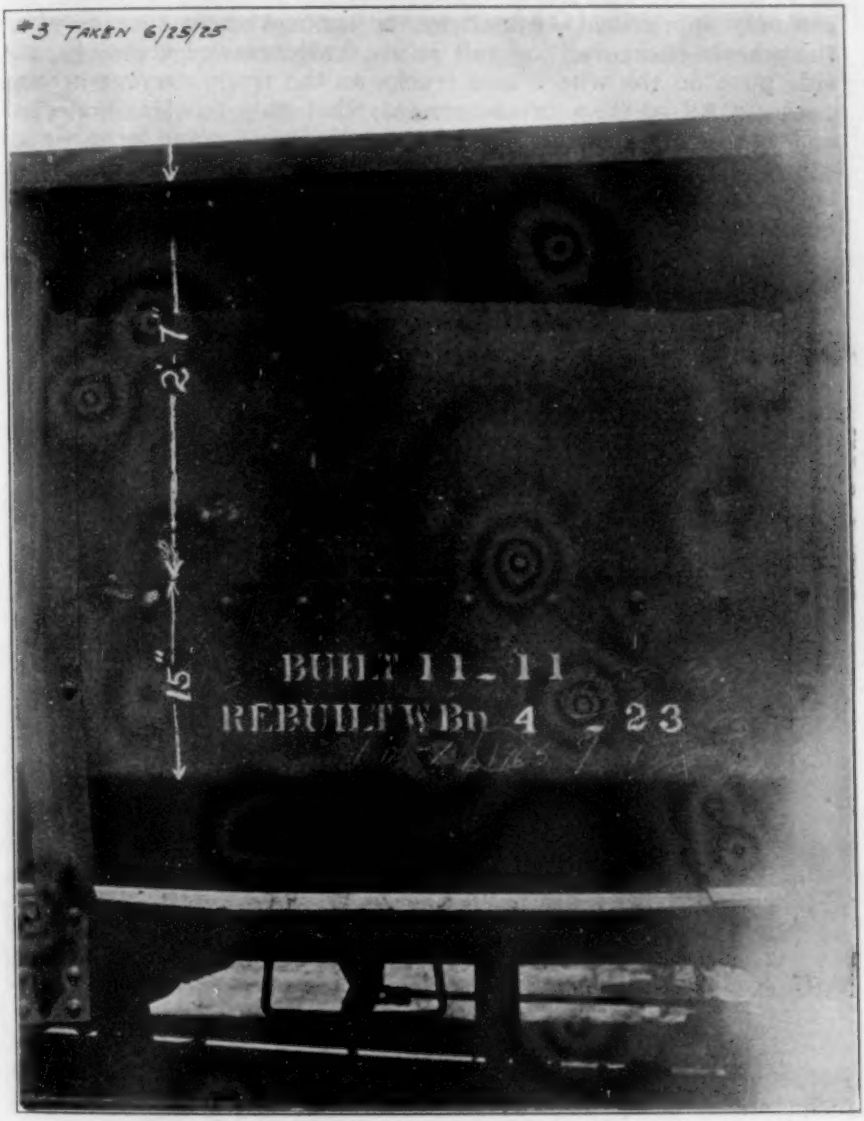

Fig. 3. Close-up of side of car showing spot welds in side stakes

It must be remembered that the vital parts of a railroad car are subjected to many varying stresses other than those due to the static loadings. Thus we have additional compressive stresses as the cars bump together, and tensile stresses as the car pull away

from each other, these actions creating an intermittent reversal of stress.

In addition to the static load stresses which are easily determinable, there are the vibratory stresses, the intensity of which we can only approximate, caused by the car movement such as when the wheels click over the rail joints, switches and crossings, the side push on the wheels and trucks as the train swerves around curves. All of these create stresses that only flawless materials and correct design can withstand. A microscopic crank may rapidly develop into a fracture and the fracturing of a vital member may result in a terrible accident, with a consequent loss of goods and life.

There are quite a few cases on record where car wheels, axles and equalizers were welded by the gas or electric arc method and

Fig. 4. Inside of car showing hard service it received

subsequently failed in service. Naturally, railroad men are very reluctant to substitute in place of riveting a welded construction which it is difficult to effectively inspect.

Another factor which the railroads must consider as regards welded connections is the matter of repairs. All the railroad car shops in the country are equipped for riveting, but not all are well equipped for autogenous welding, and in some cases they even lack the services of an experienced welder. Let us assume that a railroad, well equipped to do welding, had a welded car and that

the car was on another road and found to be in need of repairs. It might be found impracticable to repair this car by the welding process due to the foreign road not having the necessary equipment or personnel. The substitution of riveted repairs on a completely welded car might be a rather expensive procedure in that rivet holes would have to be hand drilled, or possibly an entirely new riveted construction might have to be substituted for the welded construction.

There is also a marked difference of opinion regarding the relative costs of an "all welded" and a riveted car, even if we were to assume that the car manufacturer were equally well equipped to produce either type of car.

In a welded car the costs as itemized below, would be either entirely eliminated, or greatly reduced.

A. Punching Holes.
   1. Direct labor of punching operations.
   2. Overhead costs.
      (a) Maintenance of the machines.
      (b) Power to operate the machines.
      (c) Punches and dies.
      (d) Templates, when such are necessary.

B. Drilling and reaming holes at assembly.
   1. Direct labor for these operations
   2. Overhead costs.
      (a) Maintenance of the air or electric machines.
      (b) Maintenance of the power lines to the machines, either electric lines or air lines.
      (c) Power to operate the machines, including the power losses in the supply lines.
      (d) Drills and reamers.

C. Driving rivets.
   1. Direct labor of riveting.
   2. Overhead costs.
      (a) Items similar to (a), (b) and (c) under B-2.
      (b) Rivet sets and buckers.
   3. Material cost.
      (a) Rivets.

On the other hand, welded construction entails the following costs, which do not appear in riveted construction.

A. Preparation of edges to be welded.
   1. Direct labor.
   2. Overhead.
      (a) Maintenance of the machines.
      (b) Power to operate the machines.
      (c) Tools.

B. Assembly.
   1. Cost and maintenance of jigs.

C. Welding.
   1. Direct labor.

2. Overhead costs.
   (a) Maintenance of welding apparatus and equipment.
   (b) Fuel or power.
   (c) Flux.
3. Material costs.
   (a) Welding wire.

In each of the itemized cost lists given above the relative labor cost of setting up the work has been omitted. How they would compare depends largely upon the method used and would be different for different types of work.

From the design point of view, the advantages of the welded car are:

1. The saving in weight.
2. The elimination of projecting rivet head.
3. The elimination of the necessity of overlapping at joints.
4. The ease of making joints watertight against the weather.

The immediate saving in weight effected by the use of welded construction in place of riveted construction, is, of course, due to the elimination of rivets. In the case of a 50-ton gondola car, this may amount to 400 or 500 lb. Another saving in weight is where butt-welding may be substituted for lap riveted joints. In this case there is not only the saving of the weight of the rivets but also the weight of the overlapping portion of one of the plates.

Another factor which must be considered is that a welded car would be designed quite differently from the present riveted car. The changes in the design would undoubtedly effect further appreciable savings in weight.

The significance of the saving in weight is not so much the reduction in the cost of material, but rather the decrease in dead weight hauled by the railroad. The cost of hauling the dead weight is an appreciable item in railroad expense. Although the saving in weight per car may be relatively small when we consider the great number of freight cars in constant use in this country, a saving due to hauling only one-half a ton less per car becomes a very large item.

The elimination of projections such as rivet heads is desirable in some cases. Thus in hopper cars the rivet heads in the bottom doors and sloping floor sheets offer resistance to the sliding of the lading when the car is being discharged.

The advantages of the welded car over the riveted car as mentioned above are only the apparent advantages. Undoubtedly as welding becomes more widely used in the manufacture of cars, the cars will be designed with the object in view of making full use of every favorable type of construction made possible by virtue of the adoption of welding, and many more and possibly greater advantages will appear. On the other hand, difficulties and disadvantages which are not apparent now, may also appear.

It is not reasonable to expect that welding will, in the present state of the art, supersede riveting in the construction of the under-

frame and vital parts of a railroad car. It is perfectly reasonable to expect, however, that electric spot welding may be used in applying the steel sheathing on a car. This method of fastening the sheets should be somewhat cheaper than the present riveting method.

Such a welded car is not an entirely new thing to the railroads. Although it is not so generally known, as far back as 1911 there was built an electrically spot welded freight car. A few rivets were used in this car, but only for the purpose of holding the erected members in place during the spot welding operation. This method of holding the parts was used instead of jigs on account of the savings in cost, as only one car was built.

This car was one of a lot of all-steel gondola cars built for the Chicago, Burlington & Quincy Railroad. At the request of the car builders the Chicago, Burlington & Quincy permitted them to build one car of the lot as a spot welded car.

Most of the car body of this car was spot welded. The safety appliances were, of course, riveted on. The underframe members were practically all secured together by rivets.

The car was put into service on the C., B. & Q. in November, 1911, and is known as C., B. & Q. No. 71699.

The last official inspection of this car, upon which reports are available, was in 1925. The accompanying photographs were taken at the time of that inspection. Fig. 1 shows a side view of this car. You will note the horizontal line of rivets where the side sheet had been spliced. In 1923, after 12 years of service, it was found necessary to rebuild this car. New bottom sheets and side sheets to the height as shown on the photograph, were found to be necessary. Not being equipped to do spot welding for this work, the railroad had to rivet in the new sheets. This illustrates the point mentioned above, regarding the repairing of welded cars.

The spot welding holding the side sheets to the side stakes apparently held firmly, otherwise in repairing the car these connections would have been riveted.

In Fig. 2 it is shown where two of the side stakes are riveted to the side sheet all the way up. This was done not because the welding did not hold, but in order to secure the splice plates applied on the inside of the body, as shown in Fig. 4.

Fig. 3 is a close-up of the side of the car. The spot welds in the side stakes are visible. Fig. 4 shows the inside of the car. Its condition clearly shows the hard service this car had been used in and the rusted condition of the steel. It will be noticed that there is a row of rivets on the top of the top chord of the car. These rivets were put in when the car was rebuilt in order to fasten a stiffening angle on the top chord, the car sides having bulged out.

Fig. 5 also shows the greatly corroded condition of the sheets and the spot welded construction.

It must be remembered that in 1911 welding was in its infancy and what could be done then can be done now, better and more economically. At that time welding was used very little in the car building industry. Today we weld car roof sheets, passenger

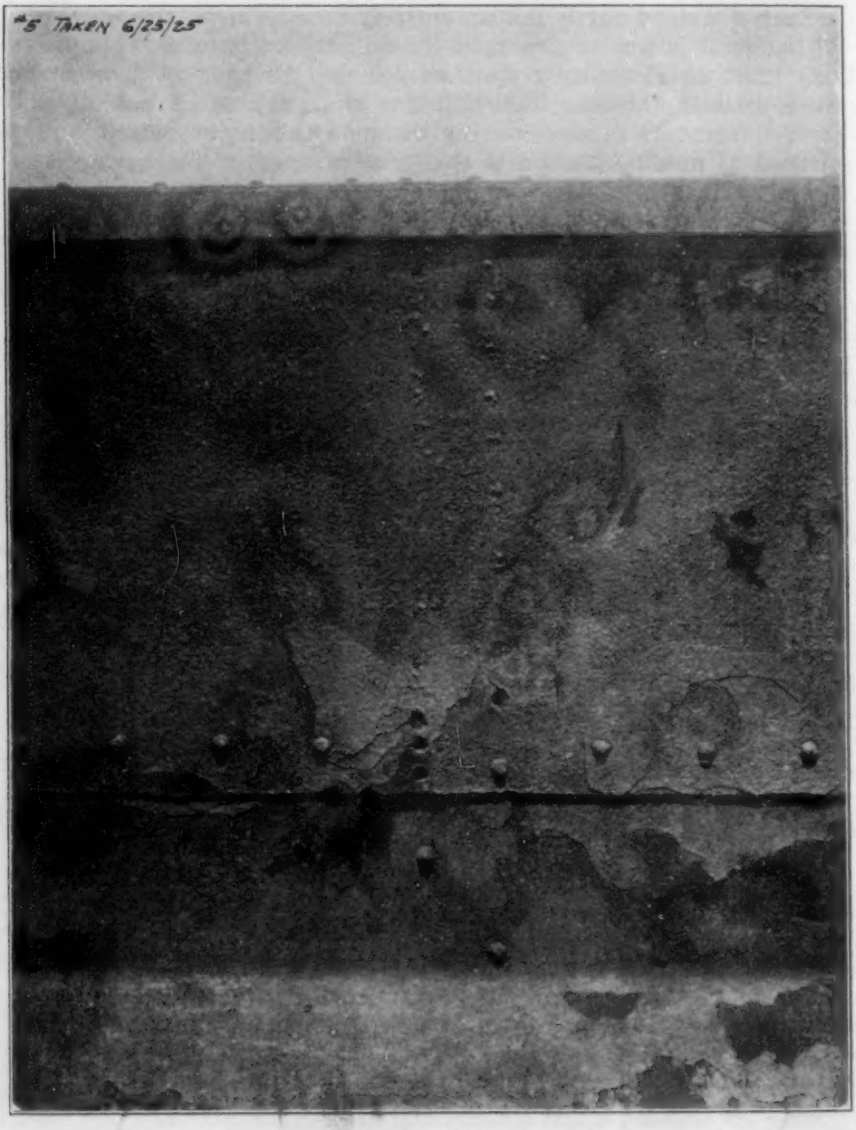

Fig. 5. Effects of corrosion

car doors, window frames, joints of letter boards, etc., and use welding extensively in the inside finish of passenger cars and for closing openings on the outside. The underframe and body of the

cars are riveted. Some welding is done on the superstructure of freight cars. For example, the A. R. A. specifies that the Zee bar side plate of their standard single sheathed box cars, Classes 4C and 4D, may be joined to the end plate by either a welded or riveted connection.

In June, 1924, the A. R. A. held its annual convention at Atlantic City, N. J. During one of the sessions devoted to the report of the Committee on Autogenous and Electric Welding, there was a considerable discussion pertaining to the application of welding in car building. In the course of this discussion J. Purcell, assistant to the vice-president of the Atchison, Topeka & Santa Fe, referring to welding as used on his road, made, in part, the following remarks:

"Now, I think the most essential thing we always do is to have first-class welders and a first-class man to supervise and see that the work is done in a first class workmanship manner.

"We have a complete set of rules governing welding. The work is done from one part of the line to the other in the same manner. Good welders can be made and they are made. We have the practice of making all our welders weld test pieces. Those are sent to our laboratories and tested for strength. Where we find bad welds those are sent back to the man who welded them. We have regular schools of welding.

"There has never been anything that the railroads have taken hold of in the past several years that is more beneficial to them than the welding, but we must do it in a first-class workmanship manner."

His remarks at this point were interrupted by applause from the railroad men present. This shows very plainly that there is no prejudice on the part of railroad men against welding, that they are not ignorant of its possibilities, and that they are apparently willing to use it more and more extensively just as fast as they feel assured that there will be no unfavorable results.

A more extensive use of welding in the construction of railroad cars must be the result of a gradual growth. The railroad men must be convinced of the desirability and effectiveness of welded construction and their convictions must be based upon the performance record of welded structures now in use.

At the same time the art of welding must progress to a point where either the skill required of the operator to make all kinds of welds perfectly has been greatly reduced, or where the possession of the skill required is so common among welders as to be deemed ordinary.

As these conditions are approached, the railroads will probably resort to a more extensive use of welding in the repair and rebuilding of cars in their own shops. This would naturally lead to the railroads demanding of the car builders a wider use of welding in car construction.

It cannot be prophesied how rapidly the art of welding in the

car building industry will increase. That depends to a large extent upon the attitude of the purchasers and users of railroad cars. The car builders must make a product that they can sell and their customer is the railroads.

Our customers must be pleased.

Welding of Automobile Parts*

W. C. HAPP†

The purpose of this paper is an attempt to explain in a general way what has been accomplished in the way of general welding practices at the South Bend Plants of The Studebaker Corporation.

Many industries do not have the opportunity to use the welding process to as much of an advantage as the automobile industry. This is probably due to two reasons—first, that the engineers who are designing the product are not as conversant with the art as they might be; and second, that the product does not lend itself as readily to the use as does such parts of an automobile as a body.

There are probably two reasons why automobile parts are welded —first, it allows a certain flexibility on the part of the designer as he knows that it is possible by welding, to fabricate a light, strong assembly;—and second, that it is cheaper. Either of these reasons is probably sufficient to warrant the use of welding, but it is very rarely that one is used without naturally affecting the other, as in overcoming a difficult design by the use of welding, it also makes a cheaper product; so on the whole, I believe that it would be very near an impracticability to try and build an automobile as we know it today, without the use of welding in some or all of its many phases.

All of the various processes, such as the oxy-acetylene, the metallic or carbon arc, the resistance or spot- and butt-weld, readily lend themselves to some phase of automobile body or chassis fabrication; and if due consideration is given the practicability of each, it is usually found that each has its own good legitimate use, as all of the processes are satisfactory for some kinds of work in the automobile industry.

No attempt will be made to try and recommend what type of welding should be used on various kinds of automobile parts; however, as a general thing, an exhaustive study should be made of each type or types of operations before assigning a method for doing them, as there are so many elements which enter into a task of this kind that it is a necessity that one should acquaint himself thoroughly with all processes.

This also holds true as to the design of welding fixtures or

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jigs which must be designed for the particular part and also for the particular process as selected. A welding jig is just as important a piece of apparatus as, for example, a machine shop jig or fixture, such as for drilling or milling or any of the other machine operations, as it is necessary that the operator continually close or open the jig to put in the work, also that the jig is of the proper design and thoroughly clamps the work; that it is not too expensive and also that it is well-designed so that the operation does not become slow or laborious.

All of the above is more or less of a general nature as it is not practical to try and qualify or make many recommendations as to any particular phase, as mentioned; neither is it wise to try and recommend any process for any general line of work.

This all brings us down to the question of the men who are to do these very necessary operations; as one of the largest problems with which any company has to deal, is that of its operating personnel.

The human element is always with us and the higher the skill of the operator, the more this becomes a problem. As welders are skilled men, this problem becomes more serious than is the case with less skilled labor and any manufacturing plant which has a large number of welders at work, finds this problem of getting good skilled men on all of the operations, quite a serious one.

This raises the point as to whether it is more economical and conducive to good results to train men in a school or hire experienced ones. In the event that it is decided that experienced men who have learned their trade at other plants are to be used, it becomes vitally necessary that some sort of a test be given these men before they are hired and put on the job, as it has been found that a great many operators believe they are skilled, when they are not and unless a test is given them, they are liable to produce bad work which may reflect back on the manufacturing plant very seriously.

At the Studebaker Corporation's plant both methods have been tried and both have their merits and problems. A school was founded and operated for a year and a great many good operators were developed. In the year we handled 500 men. Of course, a great many of them quit or went to work on other operations during this time, but it was found that by selecting young, intelligent men who expressed a desire to learn that this method produced very good results and that some of the success of our welding is due to these Studebaker-trained operators.

A school of this kind can be made almost self-supporting in a large plant, inasmuch as it is possible to fabricate a great many things which are usually purchased on the outside. A great many of these items can be made from sheet metal scrap, such as small tanks, cabinets, tool boxes, tote boxes and salvaging operations on small castings and stampings.

It was also found that by giving the men work of this kind while they were in the school, it helped to keep them interested in the job, as any man who is required to waste 100 per cent of his time practicing on scrap usually does not learn as fast as one who knows he is producing something.

A great many men have been hired who had worked at other plants and the majority of them were found to be satisfactory. However, a great many of them were good operators but needed some brushing up on the particular type of work which they intended to do, and in this case we always put them in the school for sufficient practice time before putting them on a production operation. In view of the experience as stated, the only recommendation that can be made is that a combination of hiring experienced men and training new operators is the most satisfactory for keeping up a large force of welders.

Another very good plan is to have a floor supervisor. This man must be a very experienced practical welder on the type of work which the shop is doing and it is part of his duties to try and visit each welding operation every day. We allow this man to assign the size of tips for doing each particular operation and to see that the operators do not use larger tips or drill out the correct ones. It is also part of his work to see that excessive pressures are not being used in the case of gas welding. It is the duty of the electric welding supervisor to determine that the correct voltage and amperage is used on the arc welds—to see that the proper setting is made of the butt-welding dies for panel seams—that the spot-welders are correctly set and functioning—and that the inspectors are testing the welds satisfactorily. In other words, these men are directly responsible for the quality of the work and the method, while the job is in production. They are also qualified to give any operator any little helps or instructions which may be necessary for him to better perform his job; that is, these men are so well qualified that they are able to help any operator that may need assistance.

A conclusion was arrived at that a great many of the welding operators were directly under some foremen who were not welders and were not conversant with the process; so it was decided that all of these foremen, assistant foremen and as many of the welding inspectors as possible should attend the welding school for a week's instruction. It was not the intention to train these men to become welders, but to merely familiarize them with the process. Since doing this a marked betterment has been noticed in the work as these men are now sufficiently well versed that they appreciate the problems which arise, which, before this was done, were passed unnoticed.

Welding equipment in the last two or three years—and by welding equipment, gas apparatus is referred to—has undergone some very drastic standardization moves which it is believed were accepted by every one as a very good thing, but it is believed this can

be carried farther, particularly in regard to the sizes of tip holes and threads. One of the problems with which any large manufacturer using the piecework system has to cope is the problem of using too large a tip for the work to be done. This was overcome by equipping the floor supervisor with a set of drills to fit the various tip holes, but as we are using three different makes of gas apparatus, it was found that each maker had a different standard, so it became necessary for him to carry a chart showing the difference between the three makes. This statement can probably be refuted to some extent that it would not be practical to standardize tip hole sizes due to the different types of mixing valves which are used, but, nevertheless, we believe a great deal of constructive work can be done along this line, as we found that it was much more satisfactory for us to buy one make of tip only and equip each torch with an adaptor which would accommodate the thread on the one make of tip. As we have experienced no trouble with differences in mixing valves, it is believed that very little trouble would be experienced in a standardization on tip hole and threads as suggested.

Welding wire becomes a matter of great importance when large quantites of it are being used; and it was found in order to determine that which was considered best for the job was a compromise between quality and price. It is believed that there are two requisites for welding wire. The first, of course, is strength, and the second, workability under the flame. When a test of wire is to be made at this plant sections are prepared, all being made by the same operator, using the same torch and pressure. The sample being welded on both sides of a piece of eleven gage metal. This sample is then carefully ground all over so that the cross-section of all pieces are identical—it is then pulled in a standard laboratory testing machine for strength. In the event that the wire does not work well under the torch, it is not considered, and in the event that it does work well but does not show the proper strength it, of course, is subject to the same elimination. By this method we have found it is possible to pick out good workable wire which shows a very high strength, without having to pay the extreme top price.

An attempt also is made to eleminate as many different sizes of wire as is practical. This makes for large orders for any one size, which makes it much easier to handle from all angles, particularly in the ordering and stores disbursements.

The new torches which have an automatic cut-off in handle so that the flame can be put out and the torch hung up between operations, have been found very saving in regard to gas, also the type of gas saver which consists of a hook and two cut-off valves, is very efficient. It was found that it paid large dividends to equip each operator with one of these where the work was not continuous or nearly so. This feature can best be appreciated when using tanks for each operator as it is then possible to check the consumption with and without this type of apparatus. It was found that the

operators like to use these and that it also showed, as was stated before, a remarkable saving.

In regard to arc- and spot-welding equipment. It is not believed that much can be said regarding this other than the fact that the full automatic type of spot-welder in comparison with the manually operated type is open for some controversy. It is believed that the full mechanical type is best adapted to some jobs, whereas the second type of machine is better adapted to others. As both types of machines are in use in this plant at this time on different types of operations, it is not believed practical to make a statement regarding either unless the operations were gone into in full detail.

At the time the welding school was being operated, it was found that each of the operators had acquired enough experience that they could very economically produce metal boxes for holding a complete torch and regulator equipment. These are furnished each operator and he is required to disconnect his regulators, gas saver and torch each evening and put all of the equipment into the box where it is turned over to the crib.

After spending quite a bit of time checking the causes of regulator repairs, it was noted that the vast majority of them was caused by dirt in the regulator which only could have gotten in when the regulator was disconnected. By equipping each regulator with a plug and attaching it to the regulator with a chain and requiring each operator to screw in this plug when the regulator was disconnected, their repairs were cut down approximately 50 per cent. A suggestion is offered that all manufacturers making welding regulators, fasten a plug of this kind on to all regulators and instruct the users as to the good which can be accomplished from them.

It is difficult to inspect any weld without destroying it. For that reason an inspector should be very well versed in the practice before being put on an inspection job. Of course, it is possible to pry at spot welds with a screwdriver or a similar instrument, but unless the weld is destroyed, it is never known if it is 100 per cent. It is for this reason that a great many of our inspectors have been sent to the welding school for instruction so that they will be well versed enough to be able to determine the goodness of the weld on the pieces which they supervise.

It is believed in the cases of very difficult welds that some laboratory check should be made at regular intervals to determine if the welds are satisfactory; as an example, we have what we consider a difficult weld between the shroud panel, front pillar and the shroud cross bar. This is all welded in at one time to produce the assembly. We have found that by mounting two of these securely on the floor, by placing a suitable oscillating mechanical drive between them to thoroughly strain the weld at the end of each cycle, that it was possible to cause these welds to open up and after work-

ing with this arrangement for some time, a minimum number of strokes was set as a standard.

These assemblies are selected from each operator and are marked with his check number and the date the welding was done and a report is made each week for each operator on this operation. It was found that in doing this it not only bettered the type of welds we were getting, but it created an incentive for the operators to produce better work as a report of each man's standing was made each week in the form of a chart.

It is firmly believed that if the inspection of welding is very rigid and that the operator's attention is constantly called to poor work, the standard can be raised to a much higher degree than if he is allowed to get by with poor work.

In general, it might be said that an attempt has been made by everyone concerned with welding to try and produce as good work as it is possible. Of course, the large majority of work done is on body sheet metal; however, we have welded in thousands of feet of large diameter pipe for steam and air; at a remarkable saving over a flanged or threaded joint.

Welding of broken machine parts and also brazing is practiced to a large extent, but cases of that nature are more or less special and probably could best be commented on as individual jobs.

I would like to mention at this time that we have attempted to impress upon everyone's mind that welding is not a mysterious or secret process, only to be learned by a few chosen individuals; but rather it is a very necessary art or trade and that it can be readily learned by most anyone who will apply himself. Also we attempt to explain how carbide and acetylene gas are manufactured—what oxygen is and how it is obtained—that both should be considered as expensive products, so that waste should be eliminated as much as possible.

We firmly believe that if common sense is applied to the application in the selection of the process whether oxy-acetylene or electric, welding can be made to pay large dividends.

Without a doubt welding has simplified the manufacturing of automobiles to a very marked degree.

W. C. HAPP.

PRELIMINARY REPORT

Elevated Temperature Tests of Welds

Conducted Jointly by

SAN FRANCISCO SECTION
AMERICAN WELDING SOCIETY

And

MATERIALS TESTING LABORATORY
LELAND STANFORD JUNIOR UNIVERSITY

To be presented at Annual Fall Meeting of the A. W. S., September 20th.

July 23, 1927

EDITOR'S NOTE—*The report given below covers a preliminary series of tests conducted at Leland Stanford Junior University. These tests have been made possible through the cooperation of Professor Moser of the Materials Testing Laboratory and with the sanction of Dean Hoover of the School of Engineering. The report represents the first comprehensive series of tests made at elevated temperature. The San Francisco Section of the American Welding Society provided funds for the machining of specimens and other expenses, and various member organizations have kindly loaned equipment, prepared welds and in other ways rendered substantial assistance to the local subcommittee. Representative manufacturers have furnished welding rods and the parent society has furnished the funds for the photomicrographs. Special credit is due to Professor Moser for the pains he has taken in personally conducting most of the testing work. Mr. G. O. Wilson, past chairman of the San Francisco Section of the society, under whom the work was initiated, has maintained an active and constructive interest in the work. Members of the committee consist of: K. V. Laird, chairman; J. C. Bennett, W. P. Brown, Paul Geer, Mark Haines, O. H. Kurlfinke, Verne Langford.*

OUTLINE OF TESTS

The program of tests covered, in part by this report, has four, more or less, distinct phases as follows:

1. Assembly and proofing of equipment.
2. Preliminary tests of a number of specimens for the purpose of comparing various welding rods submitted.
3. Photomicrographic and chemical studies of the specimens and rods, made in the preliminary tests and later also of the specimens in the final tests.
4. A more thorough test of a limited number of welding rods in order to more definitely define the change of properties with change in temperature.

The current report covers the first two sections of the above program.

TESTING EQUIPMENT

The equipment consisted of a 100,000 pound Olsen testing machine (Fig. 6), a Leeds-Northrup recording potentiometer pyro-

*This investigation was initiated by the American Bureau of Welding.

meter, a furnace for heating the specimens (Fig. 18), and a special extensometer for measuring elongation of the specimens (Fig. 11). Also, a jig in which to weld specimen plates (Fig. 4).

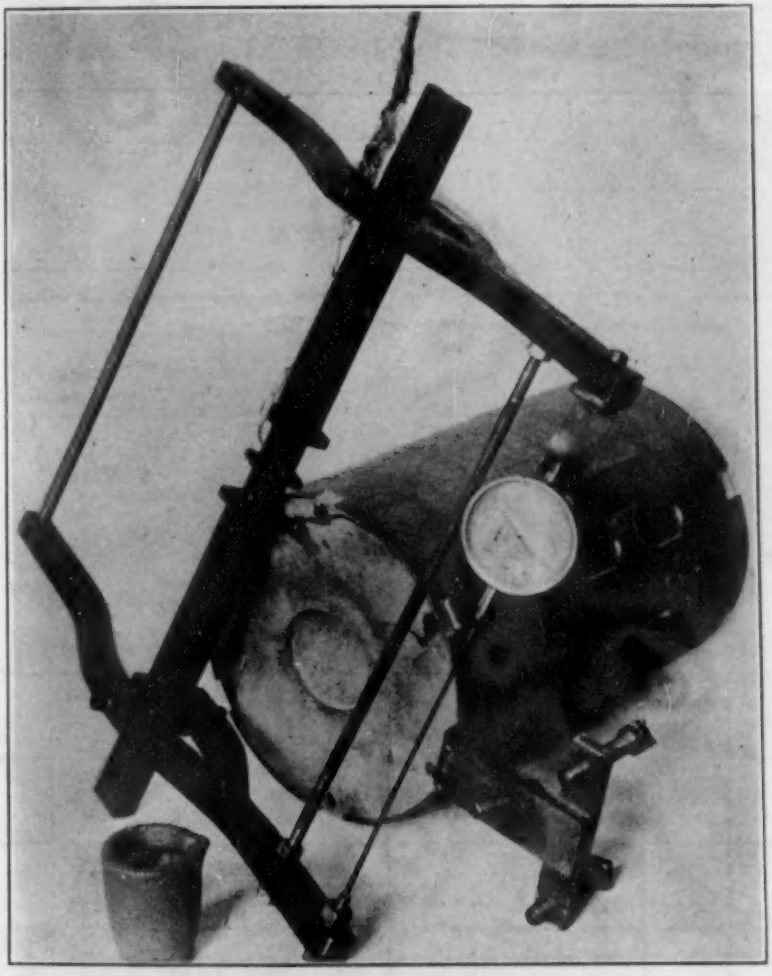
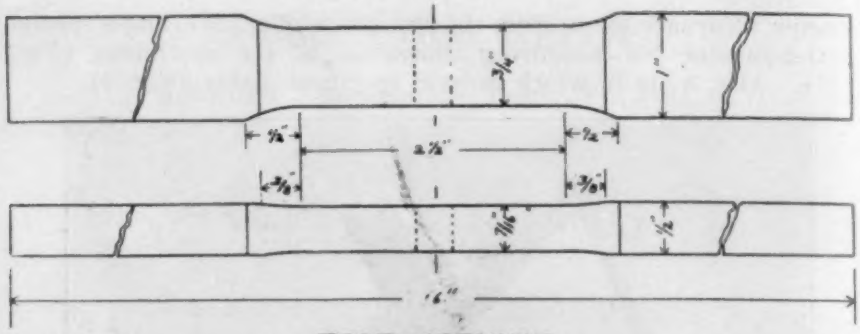


Fig. 1. Extensometer assembly showing method of applying temperature clamp and thermocouple in hole nearly through bar of the clamp. Both halves of clamp are drilled, allowing application of one thermocouple to each side of specimen if desired

The testing machine is in first class shape, having been checked for accuracy prior to the tests. The pyrometer equipment has been checked against Bureau of Standards standard temperature melting point metal. The extensometer was built to use one dial and to multiply the extension by two on the indicator. This has the advantage of simplifying the taking of readings and at the same time gives a high degree of sensibility, sufficient, with an Ames dial reading to 1/10,000 in., to afford more than the necessary accuracy.



TEST SPECIMEN

The Weld to be of either type "A" or "B" as detailed. Remove rugged corners on machined section with sharp file and shanks by grinding. Grind welds to approximately flush with surface before machining wide faces and feed cutter slowly

Fig. 2

SKETCH 2.

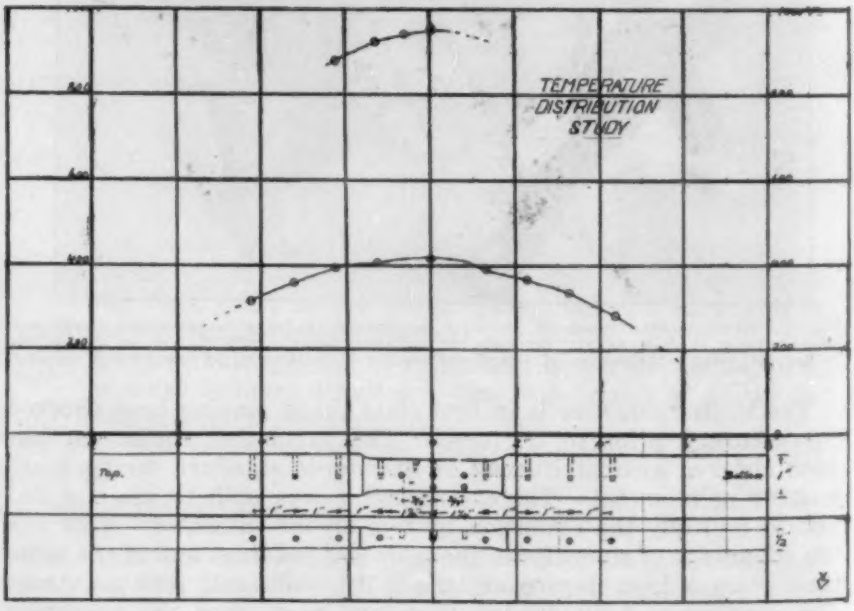


Fig. 3

The furnace was designed for the work and has a concentration of the element near each end, which, together with the control used (Fig. 6), afforded a convenient means of considerably flattening the temperature distribution curve of the specimen. A small graphite crucible was used (Fig. 1) in this furnace for making the pyrometer melting point checks.

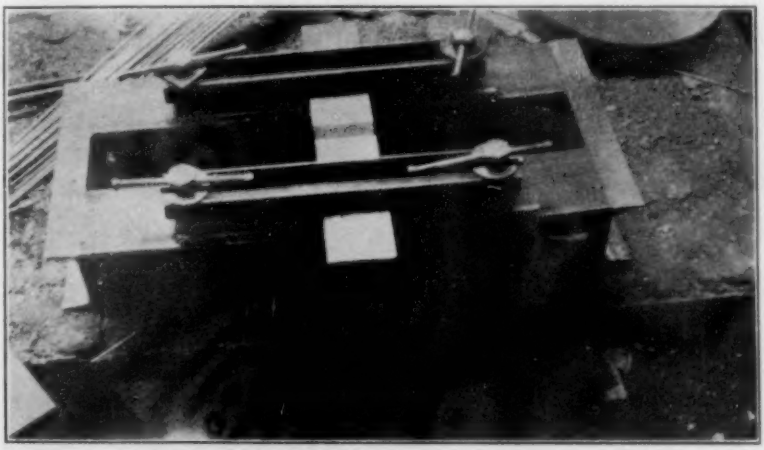


Fig. 4. Jig for insuring alignment of specimen plates

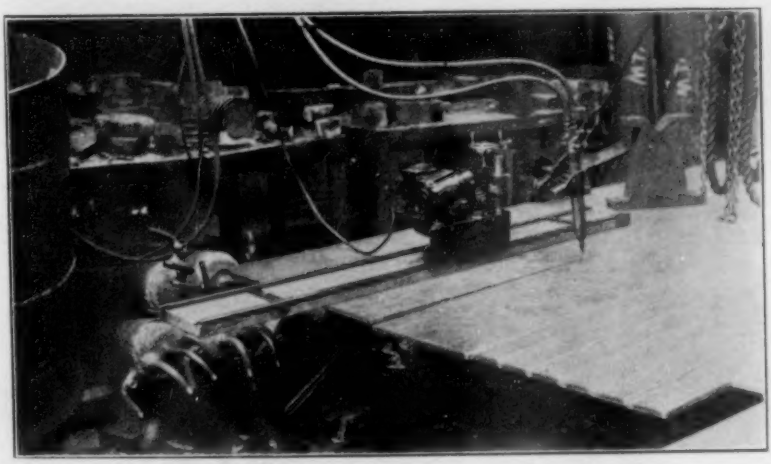


Fig. 5. Cutting steel sheet into specimen plates

The question of taking the temperature of specimens was one which had to be worked out before any actual testing could be entered upon. The fact that the specimens were to be welded focused the attention upon the necessity for taking the temperature *at the weld*, which was approximately at the center, of length of the specimen. For comparative purposes a machined specimen was necessary, therefore no excess metal was available at the weld

to offset even a very small hole for the placing of a thermocouple.

Some thought and experiment were given to this point and the device illustrated in Fig. 1 was developed. The expected inaccuracy of an exposed thermocouple, either adjacent to or in actual contact with the specimen, was verified as the preparation progressed.

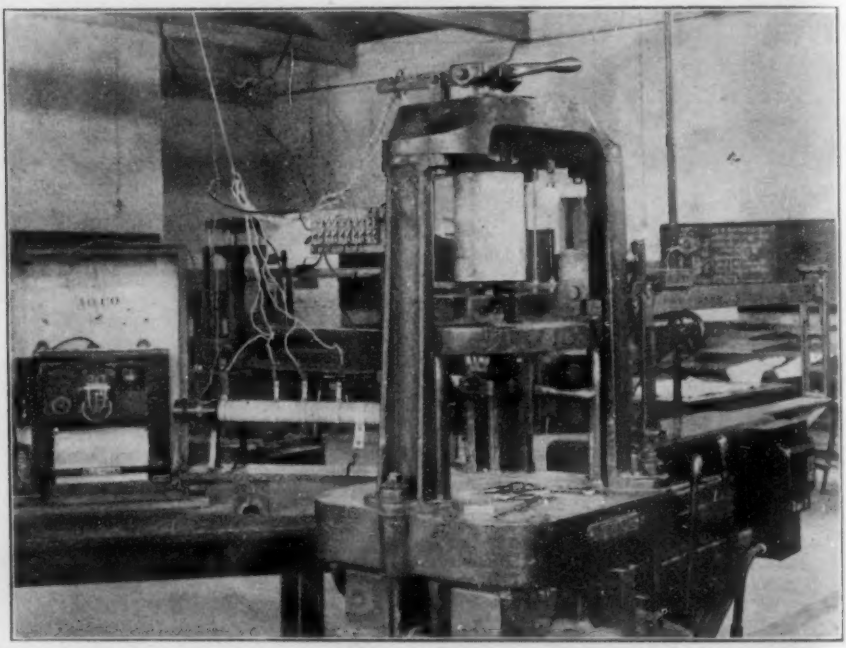


Fig. 6. General view of testing equipment

The clamp finally adopted had the following salient features in connection with its application:

1. Supported entirely upon the specimen itself.
2. Care was taken that each test was started with bright clean surfaces in firm contact.
3. Tests showed the clamp to be 6 deg. Fahr. hotter than the center of the specimen at approximately 950 deg. Fahr.
4. While specimens tested to date at temperature have been for the most part near 900 deg.-950 deg. Fahr., checks have shown this six deg. difference to decrease uniformly with decrease in temperature.
5. The clamp must be cleaned of heat color or oxidation of the contact surface for each new test. A second heat upon a set up of specimen and clamp without cleaning of either showed a 12 deg. Fahr. difference between specimen and clamp where the first trial showed 6 deg. Fahr.
6. The clamp in no case showed a tendency to become loosened,

The above relationships and the temperature distribution in the specimen Fig. 3, were worked out using a substitute specimen made from the same metal used in the test specimens and of the same dimensions. This specimen is shown at the bottom of Fig. 10. Thermocouples were made of Leeds-Northrup No. 20 wire.

The design of specimen Fig. 2 was chosen for general practicability. The fact is that the same type has been previously used,* and that it is of compact section, and subject to smaller tempera-

*Bureau of Standards Technical Papers No. 205, No. 219 and Symposium, Joint Meeting A.S.M.E. and A.S.T.M., May 29, 1924.

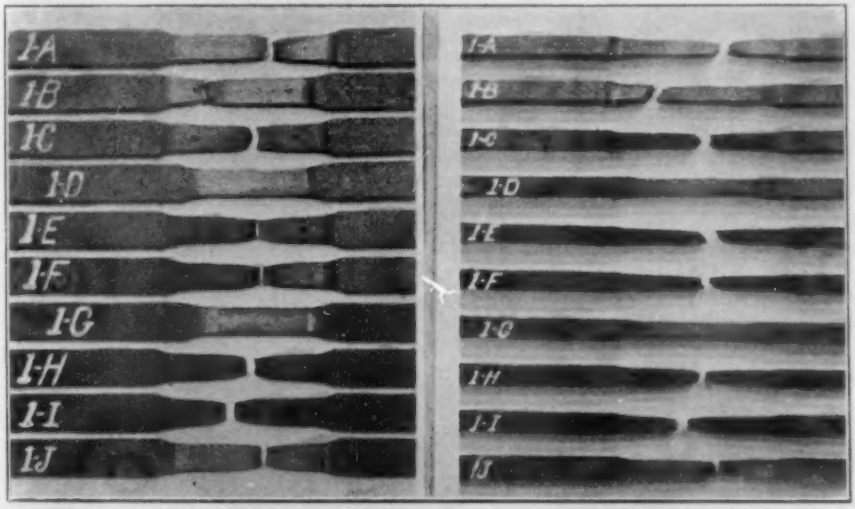


Fig. 7. No. 1 set of original metal specimens. See Fig. 17 for data

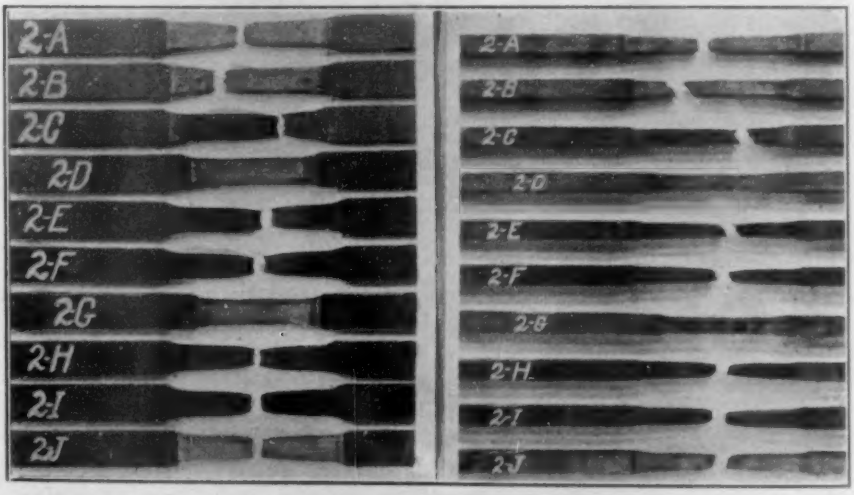


Fig. 8. No. 2 set of original metal specimens. See Fig. 17 for data

ture variations within its section than would be the case with a wider and perhaps thinner section when exposed to radiation from hot furnace walls. This would be especially true if the circular furnace section were retained.

PREPARATION OF SPECIMENS AND DISCUSSION.

Specimens were prepared by machining from plates cut from a 5 ft. x 10 ft. sheet of ½ in. fire box steel purchased in the open market. The location of each plate was recorded so that the position of the part of any specimen can be exactly located in the original sheet should occasion demand. Over ½ of the sheet is retained for reference purposes or further extension of the tests without introducing the factors represented in a new sheet.

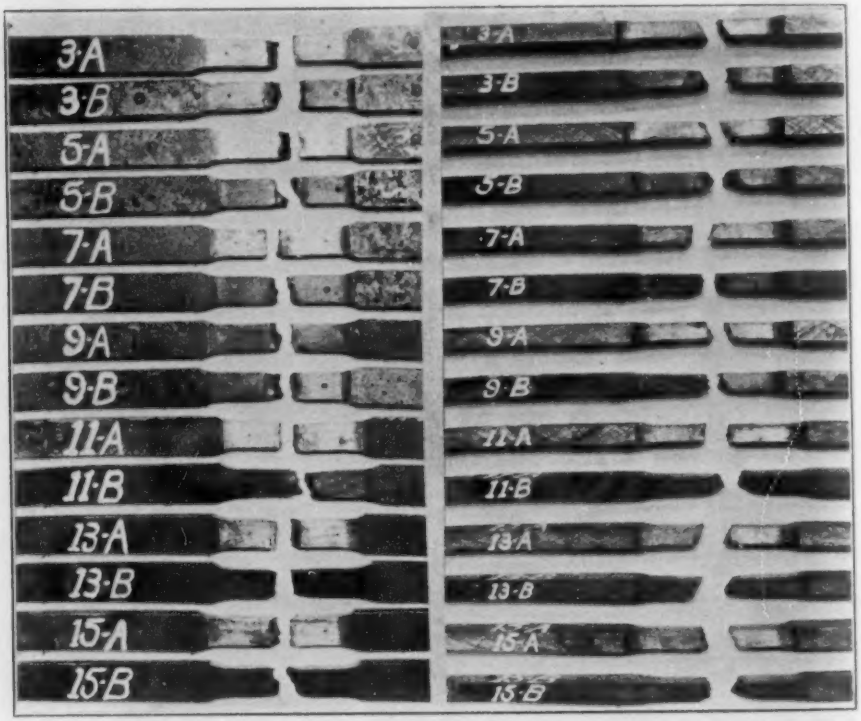


Fig. 9. Electric-welded specimens. Note square breaks and lack of ductility

Each specimen plate was numbered before being cut from the original sheet and each specimen before being cut from the smaller plate.

The specimen plates (Fig. 12) were of three sizes. The 12 in. x 16 in. largest were cut into ten 1 in. x 16 in. specimens for test of the original metal. The smallest, 3 in. x 8 in. for welding into 3 in. x 16 in. welded plates and later cut into two 1 in. x 16 in. welded specimens. The intermediate size of 8 in. x 12 in. are being

held for the specialized tests and are to be welded into 12 in. x 16 in. plates to be cut into ten 1 in. x 16 in. welded specimens. Thus all the individual test specimens whether welded or not will be of the same size.

The cutting of these plates from the large sheet was accomplished with a cutting torch mechanically driven. While this gave

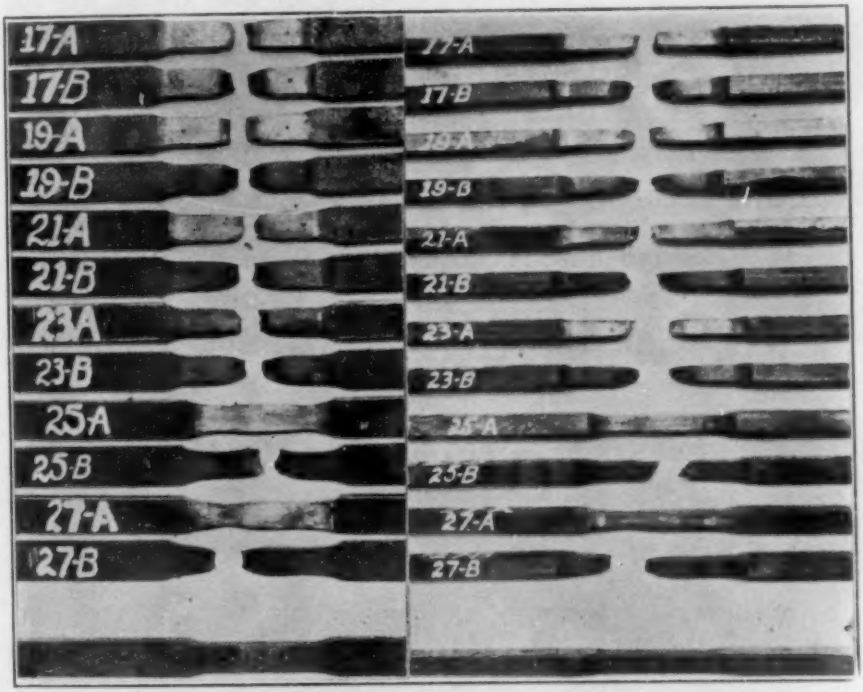


Fig. 10. Gas welded specimens and temperature distribution specimens. Note ductility and unbreakable welds

a very smooth, uniform cut, there was some question as to the effect of heat of this cutting operation on the finished specimens.

The answer to this question is graphically shown in the photomicrograph (Fig. 13), where the maximum penetration is found to be about 0.06 in. The flame was directed downward, the vertical edge being that cut by the torch and the horizontal edge the original surface of the plate. The cutting away of the corner shows the action of the preheating flame.

While there is no deep structural alteration due to the torch cutting, as shown by the photomicrograph, later experience showed that serious mechanical stresses were introduced. The individual specimens, when stripped from the plates by means of the torch warped and had to be straightened. Stripping into 1 in. widths for specimens was therefore done by milling. The center or reduced section of all specimens was machined parallel to within .001 in.

The metal removed in this machining was sufficient to clear specimen of any metal which had been altered in the torch cutting.

In the few cases where it was necessary to straighten a specimen due to warping or misalignment in welding, this was done in a large vise and gripped in such a manner as to avoid bending the weld or metal adjacent to it.

All of the electric welds were made by one man and all but one of the acetylene welds were made by one welder. The one exception being (specimens 25 A-B) a relatively new special rod for which the manufacturer supplied a welder. The plan of having one welder do each type of weld was resorted to in order to insure, in so far as possible within the scope of the work, uniformity of the work done.

The man chosen in each case was a welder of especial and recognized ability, subject to frequent test and under skilled supervision.

The fire box steel used in making the specimens had the following characteristics:

	Mfrs. Data	Local Test
Heat No.	10,375	
Analysis		
Carbon	.18	.139
Manganese	.48	.47
Phosphorus	.018	.010
Sulphur	.027	.019
Silicon	...	.023
Chromium	...	None
Nickel	...	None
Yield Point	38,200	...
Proportional Limit	...	21,000 to 31,000
Tensile Strength	61,540	66,500 to 68,250
Elongation 8 in.	.27	...
Elongation 2 in.	...	.375

The welding rods submitted were, for convenience, classified as shown in the tabulation Fig. 14. There were five groups, the first, Low Carbon Gas, falling within, or intended to fall within, the "G-1" specification of the Society. The second Low Carbon Electrodes corresponding to "E-1-A" specification. The third falling within specification "E-1-B." The remaining two classifications had some special feature such as coating or other special distinction and were for convenience divided into electrodes and gas rods.

Of the four electrodes thus thrown together there was probably little in their performance to distinguish them from the other electrodes, two appearing to be high carbon and two low carbon. Each of the three gas rods, however, was of a special nature, the No. 1 being a self-fluxing rod, No. 15 contained Vanadium and No. 24 contained Nickel.

No electrodes comparable to these last three gas rods were sub-

mitted, which is regrettable as some tests which one of the writers made several years ago indicated that a nickel alloy electrode can be made to do some very fine work.

The results represented in Fig. 14 are best studied in graphic form in Fig. 15 and Fig. 16, where they are shown in connection with the properties of the original metal. Fig. 14 is a plot of the ultimate tensile strength against temperature, the continuous curve being plotted from the two sets of original metal specimens tested (Fig. 17).

Each broken line joins two points one of which represents a hot and the other a cold specimen tested roughly at the two extremes of the test range. This was done in order to get a rough compari-

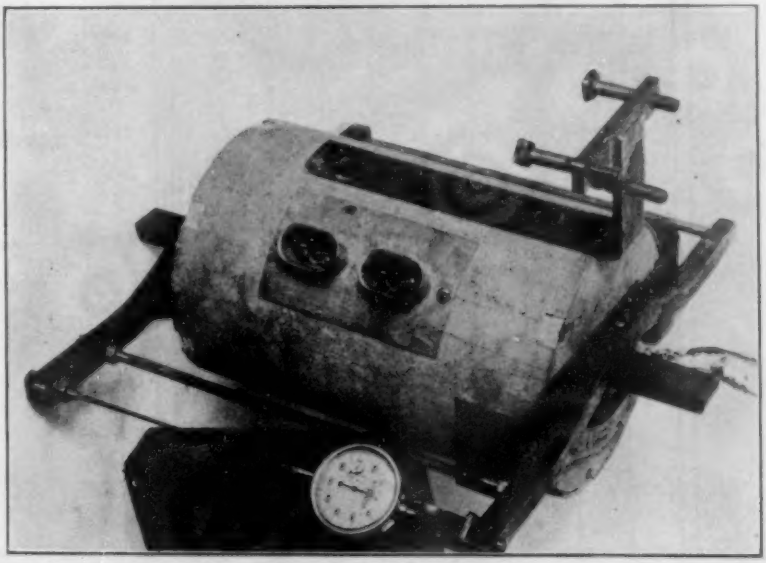


Fig. 11. Furnace, extensometer and specimens assembled

son from as many welding rods as possible. It will be noted in Fig. 14 that in the three "specification" classifications representative rods only were tested. This was done as it was not possible to carry through the test routine on all rods submitted. The choice was made, however, so that a number in proportion to the number submitted were tested in each classification and it was also found possible to make the choice so as to test at least one rod from each manufacturer.

While it may appear regrettable that all the samples submitted were not tested it must be borne in mind that the purpose of the work was to get representative information with the time and personnel available.

It was not possible to run duplicates in the tests shown in Fig. 14, because this tabulation together with Figure 17 represents

ninety-five hours of time with specimens actually under test in the machine, to say nothing of the time spent in preparation. This fact with the preliminary nature of this phase of the work made such a course necessary.

Returning to Fig. 15 the fact stands out clearly that the set of results on hot welded specimens appear consistent with the curve

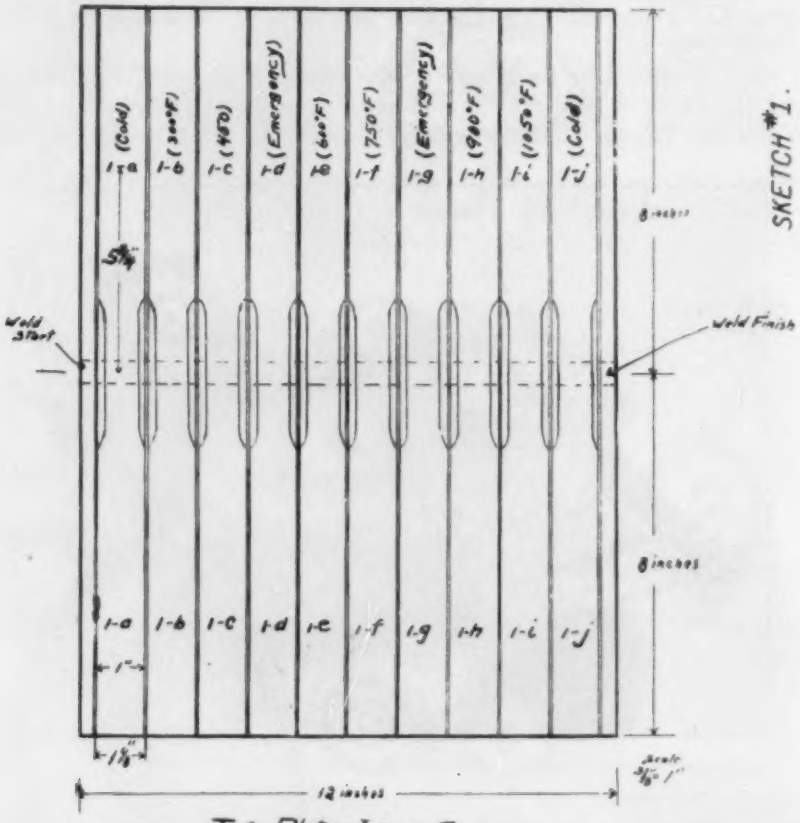

SKETCH #1.
1-a (Cold)
1-b (300°F)
1-c (450)
1-d (Emergency)
1-e (600°F)
1-f (750°F)
1-g (Emergency)
1-h (900°F)
1-i (1050°F)
1-j (Cold)
Weld Start
Weld Finish
8 inches
12 inches
Test Plate Lay-out.
Two pieces 8"x12" welded to make plate 16"x12". Lay out 1⅛" allowing ⅛" for cut in stripping - finished specimen to be 1" wide. Mark from left to right 1-a, 1-b, 1-c ..... 1-i, 1-j. The numeral indicating test plate number and letter position and sequence of specimen as indicated. Plate halves to be roughed out with Torch 12" x 8".

Fig. 12

obtained from the original metal specimens and similarly with the cold welded specimens.

The welding rod designated in the tests as No. 1 gave a singular performance which may be accounted for in either of two ways: 1st, the specimen happened to be made from a stronger part of the plate than the reference specimens. 2nd, that the presence of

the strong weld in the center of the reduced sections so shortened the space within which reduction of area took place that a higher value of tension was required to break the specimen. In any event no apology need be made for the quality of the weld.

It will be noted that the three special gas rods stand very high in Fig. 15.

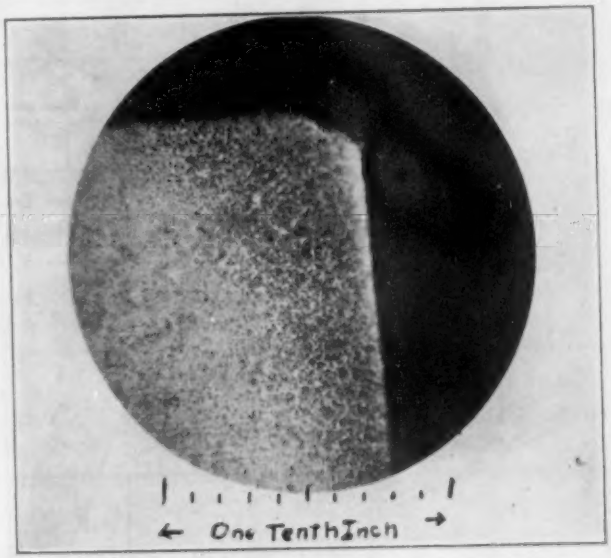


Fig. 13. Photomicrograph of torch cut margin. Note that alteration of structure does not penetrate more than .06 inch

ROUGH DRAFT OF RESULTS @ PRELIMINARY PROGRAM.
TESTS OF WELDS AT HIGH TEMPERATURE.

(Subject to correction upon checking calculations and applying temperature corrections).

Type of Welding Rod.	Welding Rod Number	Carbon Content %	Cold. Prop. Limit #/in²	Cold. Ultimate Strength #/in²	Cold. Specimen Number	Cold. Temp. °F.	Cold. Prop. Limit #/in²	Cold. Ultimate Strength #/in²	Cold. Elong. 4-D°	Cold. Red. Area %	Hot. Specimen Number.	Hot. Temp. °F.	Hot. Prop. Limit #/in²	Hot. Ultimate Strength #/in²	Hot. Elong. 4-D°	Hot. Red. Area %
Low Carbon Gas Rod. .08 C. Max.	3	.089	48,350	81,400	17-18-4	65	27,000	60,400	15.0	30.2	17-18-3	950	7,300	30,250	25.0	67.5
	6	.082	38,800	49,700	23-24-4	65	29,000	61,000	17.0	32.6	23-24-3	956	9,200	33,000	31.0	77.3
	8	.055	46,800	61,400	" "	"	X	" "	"	"	" "	"	"	" "	"	"
	10	.058	47,400	62,800	" "	"	"	" "	"	"	" "	"	"	" "	"	"
	13	.055	50,800	63,350	19-20-4	65	27,300	54,050	18.0	31.9	19-20-3	957	5,000	28,700	27.5	79.50
	16	.075	56,400	69,700	" "	"	" "	" "	"	"	" "	"	"	" "	"	"
	22	.062	55,600	66,100	" "	"	" "	" "	"	"	" "	"	"	" "	"	"
	25	.062	65,500	66,700	" "	"	" "	" "	"	"	" "	"	"	" "	"	"
Low Carbon Electrodes E-1-A .08Max	2	.055	69,200	79,050	" "	"	" "	" "	"	"	" "	"	"	" "	"	"
	11	.082	62,850	69,250	9-10-4	75	26,000	57,100	4.5	4.9	9-10-3	900-905	9,200	35,650	15.0	27.5
	14	.056	40,800	74,250	" "	"	" "	" "	"	"	" "	"	"	" "	"	"
High Carbon Electrodes E-1-B .15 to .18	2	.194	68,700	95,100	" "	"	" "	" "	"	"	" "	"	"	" "	"	"
	9	.151	62,000	85,750	15-16-4	75	27,500	55,650	5.0	4.9	15-16-3	910-893	10,500	37,000	10.0	7.3 *
	12	.138	55,300	85,000	" "	"	" "	" "	"	"	" "	"	"	" "	"	"
	20	.031	90,500	110,900	" "	"	" "	" "	"	"	" "	"	"	" "	"	"
	21	.144	56,000	78,150	15-16-4	80	33,250	56,700	5.0	4.3	15-16-3	908-903	10,000	41,000	12.5	27.1
Special Rods Gas.	1	-	66,300	115,200	27-28-4	60	28,000	78,000	X	X	27-28-3	906-910	12,700	48,400	X	X **
	15	-	54,200	85,000	23-22-4	65	29,000	62,200	18.0	30.2	23-22-3	930	13,400	36,050	26.5	59.96
	24	-	55,200	122,750	27-28-4	65	27,000	68,900	X	X	27-28-3	957	7,500	36,000	X	X
Special Rods Electrodes	5	-	53,300	77,450	5- 6-4	73	24,000	53,000	6.5	5.7	5- 6-3	911-909	9,500	31,700	12.0	20.4
	17	-	55,000	72,200	3- 4-4	73	25,000	57,400	6.25	5.8	3- 4-3	896-900	14,000	30,250	16.0	16.1
	18	-	57,500	109,600	11-12-4	68	25,000	58,400	9.0	9.15	11-12-3	910-903-910	8,500	40,950	27.5	30.8
	19	-	61,900	87,400	7- 8-4	72	33,500	73,100	4.5	5.98	7- 8-3	911-906	9,000	30,900	10.0	14.4

X Specimen not broken in the weld, or elongation in chuck.
* Tearing break.
** Elongation mostly outside weld.

Figur 14.

Fig. 14

The proportional limit of a welded specimen is somewhat of an uncertainty since the usual method of taking such data does not distinguish between the value for the welded metal itself and that of the original metal included between the points of attachment of the extensometer, in this case two inches apart.

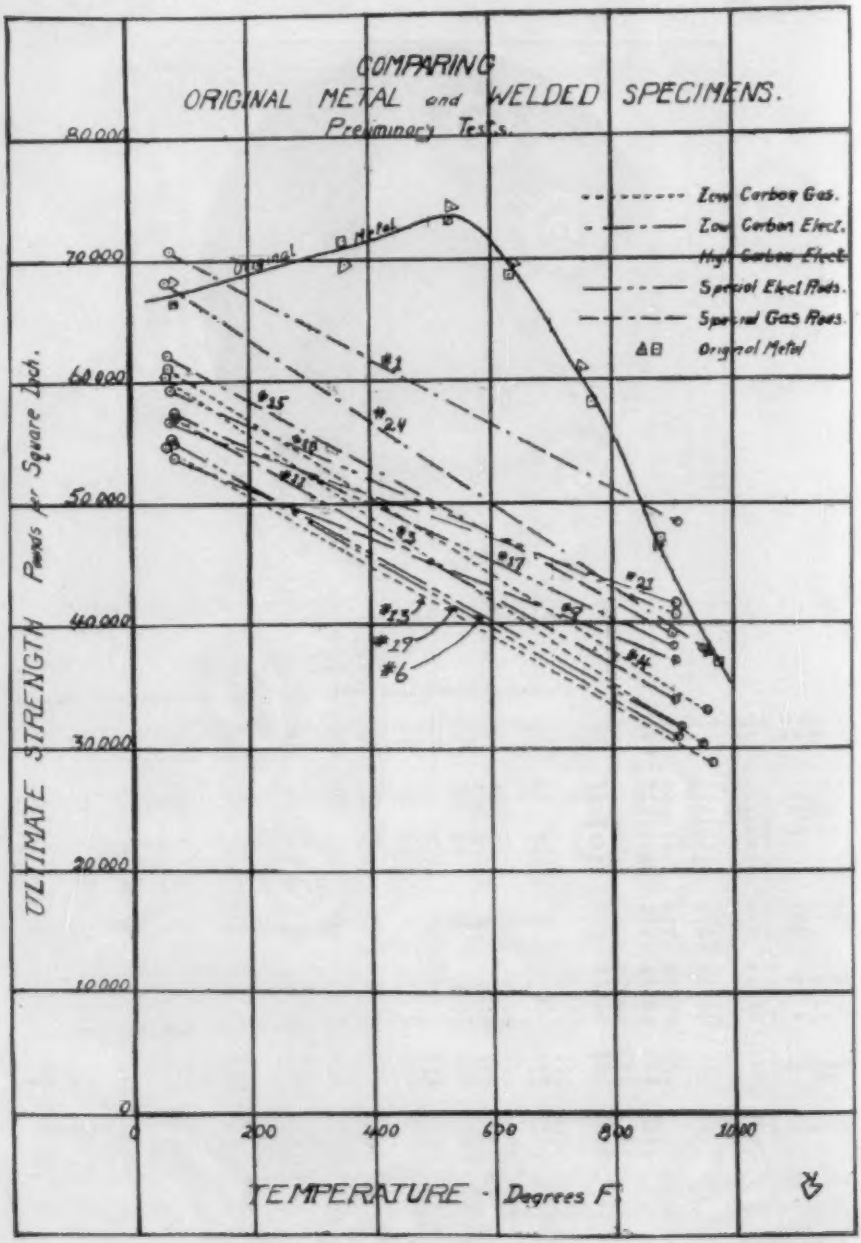


Fig. 15

The variation of proportional limit values obtained with the cold specimens of original metal was not expected and will make it necessary to use the "emergency" specimens left in each plate for further test. The consistent results shown at elevated temperatures are gratifying. These points are well brought out in Fig. 16.

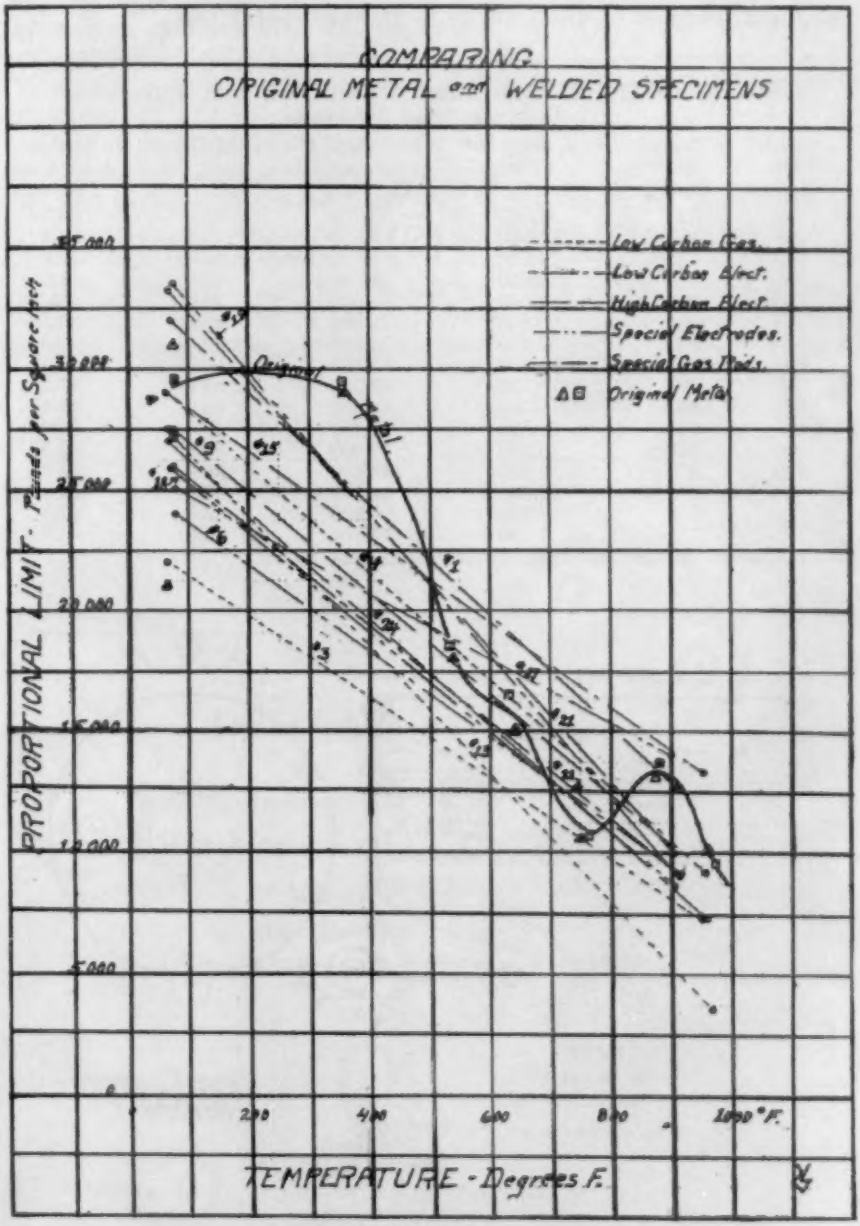


Fig. 16

The data summarized in Figs. 15 and 16 together with the further information gained from photomicrographs will be used as a basis for choice of material for further specimen plates.

These will afford a more complete temperature range test (comparable with the curves shown for original metal in the two figures referred to) but embracing only three or four types of welding material instead of thirteen as in the two point tests.

ROUGH DRAFT OF RESULTS OF PRELIMINARY PROGRAM
Original Metal Specimens

Specimen Number	Temperature, Deg. F.	Prop. Limit, Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent/2 In.	Reduction Area, Per Cent
1-A	75	31,000	68,250	37.5	51.5
1-J	61	21,000	67,850	40.6	51.4
2-A	75	27,200	66,600	42.2	57.0
2-J	75	29,500	66,500	40.0	51.9
1-B	360	29,000	69,500	24.0	32.4*
2-B	355	29,500	71,400	22.5	30.1*
1-C	539	18,000	74,250	26.0	33.9
2-C	532	18,500	73,250	17.5	26.0*
1-E	638	15,100	69,500	34.0	47.1
2-E	632	16,500	68,650	32.5	46.1
1-F	750	10,600	61,100	38.5	58.9
2-F	768	10,700	58,200	38.5	62.2
1-H	872	13,000	46,500	36.0	62.3
2-H	879	13,600	47,150	38.0	61.0
1-I	959	10,000	37,900	39.0	63.6
2-I	972	9,500	37,000	40.0	64.6

*Reduction in area partially outside 2 in. test length.

Fig. 17

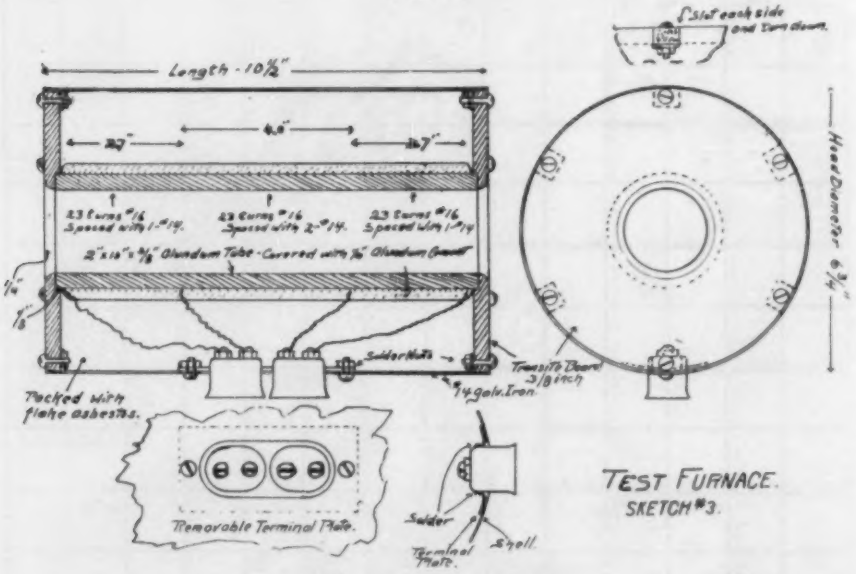


Figure 18.

In this connection it is well to note that the character of scarf of the plate will influence the manner of failure of a weld.

Conclusions

It is premature to form major conclusions at this time when the data is as yet incomplete.

1. The self-fluxing rod (Specimens 25-26 A, B) has shown remarkable properties and will no doubt form the basis for some very interesting detailed studies.

2. A study of the tabulation in Fig. 14 leads to the following deductions:

a. As far as ultimate strength is concerned a strong weld cold is in general also a strong weld hot.

b. The same is not as consistently true of the proportional limit figures which appear to require more than one point per condition to be conclusive.

3. The fracture of a single scarf weld in a hot specimen gives evidence of originating at the narrow or bottom side of the weld and progressing to the opposite surface.

KENNETH V. LAND.
CHARLES MOSER.

Discussion of Papers!

Written discussion of papers to be presented at fall meeting is invited. If received before the meeting, it will be read at the meeting and later printed in the Journal—in any event it will be printed in the Journal.

Arc-Welding in Buildings*

JOSEPH MATTE, JR.†

The use of arc-welding in buildings requires cooperation between the welder and the structural engineer which cannot exist unless each party understands clearly the other's point of view. The purpose of this paper is to describe a structural engineer's experiences in the field of welding, to give his point of view on the subject and to make some suggestions which may be of assistance.

In 1916 I had occasion to design the construction work of a small one-story factory, the roof of which I proposed to support on gas pipe columns. I undertook to show on the plans a suitable detail for the cap and for the base of these columns. I found two or three more or less plausible solutions, but they seemed quite awkward. A mechanical engineer who had already had some experience in pipe welding suggested that the cap and the base could be readily welded to the columns. A sample was made up and found to be by far the neatest and cheapest solution. (Fig. 1.) It was adopted. Since then I venture to say that all our columns have been provided with welded caps and bases. I know that within the last year we constructed a large transit warehouse supported on pipe columns and that all these columns are provided with welded caps and bases.

My next experience was with some steel stairs. A miscellaneous iron contractor proposed welding the treads and risers to the stringers, to notch the newel posts and to weld them also to the stringers. I thought that proposition over and it worried me. I finally allowed him to weld the risers and the newels to the stringers. I also allowed that the treads be welded to clip angles connecting them to the stringers, but these clip angles had to be riveted to the stringers. (Fig. 2). I have an idea that the contractor in question went away disappointed. Evidently I had less confidence then in the load carrying value of welds than I have now.

The next thing to do was to get some tests results to see what might be expected of welds for carrying loads. I could get no such information at first, but eventually found some reports of work done in England and in Germany which showed minimum values of around 27,000 lb. per square inch in shear. For the first time I had some definite information to go by.

Later the shop details of a large steel stack were sent into our office to be checked. This stack was to be lined for, perhaps, half its height with firefelt. To support the lining we had specified that the stack plates be drilled with 7/16 diameter holes placed about 2 ft. apart around the girth of the stack to allow bolting on small angles every 3 ft., vertically. The shop details showed these small angles tack-welded about 12 in. on center to the stack plates.

*To be presented at Annual Fall Meeting of A. W. S., September 22, 1927.
†Construction Engineer, Albert Kahn, Incorporated, Detroit, Mich.

The firefelt carried by the angles being very light, the question of load had practically nothing to do with the subject: so the welded design was allowed. (Fig. 3). I was much impressed with the large amount of handling, drilling and punching which was eliminated in the shop by this simple expedient.

When subsequently a firebrick lined steel stack was submitted with the same tack-welded lining supports, it was noted that the loads on the tack welds were again negligible. An objection was made this time that the high temperature in the stack might have an effect on the welds. It was pointed out that the temperature was six times greater at the welds when they were put on than it ever could be afterward and with that the design was allowed.

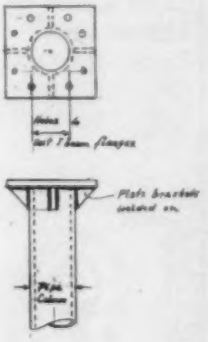
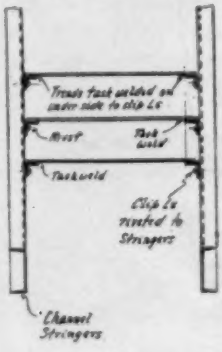


Fig. 1.
Welded cap for column



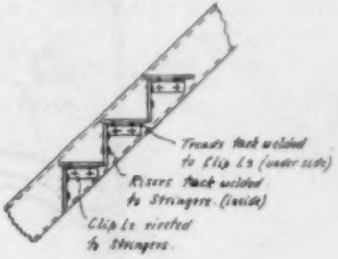


Fig. 2.
Welded treads and risers

Several other stacks were subsequently detailed with such tack welds and approved. We finally began to specify that all lining rings were to be tack-welded in place.

You will observe that up to now the welders were coming to me and that they were the ones who were proposing welding for some purposes that seemed more advantageously handled in that manner.

As I look back today I can see that a number of problems which came up in those days would have been solved very simply if welding had been used. But I did not think of it. I had not learned yet to carry with me the idea of welding just as I carried the idea of riveting or bolting, so that welding would suggest itself naturally when it gave the right solution. For instance, many buildings had to be designed for eight, ten or twelve stories, but only three or four stories were to be built at first. The columns of such buildings, when steel, were habitually run up about 2 ft. above the temporary roof line so that splice plates could later be provided to bolt or rivet the future column sections to the existing ones. That meant that the owner had to pay for many 2 ft. pieces of columns which he did not need in the least at the time, and chiefly that some very awkward, and consequently expensive,

waterproofing and flashing had to be provided around the projecting column stubs. (Fig. 4). It occurred to me eventually that a much simpler solution was to stop the steel columns flush with the temporary roof construction, the waterproofing running straight across in one unbroken expanse, and if, later, it was desired to extend the building, to remove the waterproofing and weld on the next column sections to the existing ones. (Fig. 5.) That seems

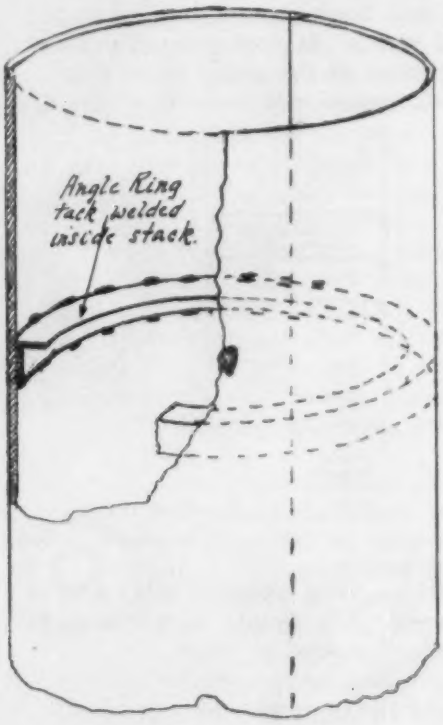


Fig. 3.

Welding angle ring in stack

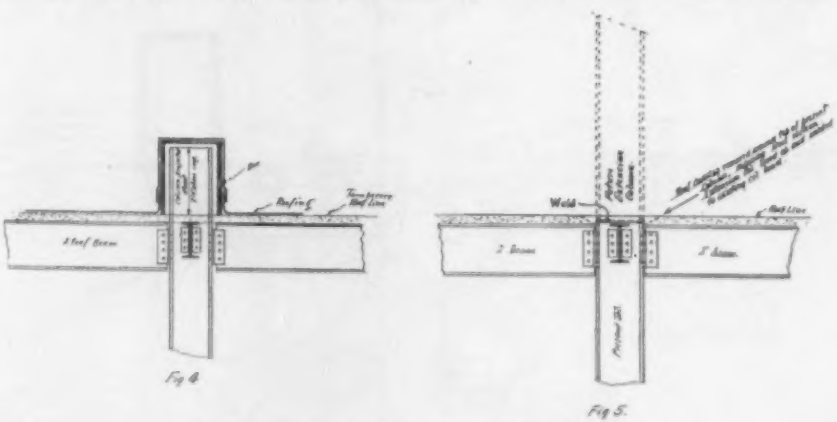
rather obvious; nevertheless I saw a building only a few days ago in which the old design is being used.

The same solution applies to reinforced concrete buildings. Formerly the rods of the topmost section were either run up and boxed in or bent down and parged with concrete, the roofing being humped over the parged areas. (Fig. 6.) A better way is to anchor a small plate in the top of the column flush with the roof slab, anchored to the column below and run the waterproofing across without interruption. Later, if the building is to be extended the rods for the next column section can be built up as a

unit, set in place and the bottom of the rods welded to the plate. (Fig. 7.)

Those earlier experiences had given me food for thought and once started the idea kept growing. The day came when I began going to the welders instead of their coming to me.

A large jobbing foundry was planned and one of the requirements was that we guarantee the charging floor against leakage. It was pointed out that in another foundry of the same plant a large charging floor had been built and that to protect the space below from leakage above, the steel frame had been covered with a 12-in. concrete slab haunched down to the bottom flange of the beams and girders and that the wearing steel plates had been laid on top of that. (Fig. 8.) This floor was reported as leaking and no such design was to be considered. To meet the requirements the obvious solution was to eliminate the concrete, thereby saving



Provision for extending columns in a building

much formwork and steel and to weld the floor plates directly to the supporting beams. This was done. The cross joints were welded to each other over copper bars placed below temporarily. (Fig. 9.) I examined this floor later, found stagnant pools of water on it and on the joints, but there had been no leakage.

Shortly afterward five slurry tanks were erected in connection with a cement plant. These tanks were riveted and caulked. When they were tested with water they leaked considerably. One of them was re-caulked. When tested again it leaked. This sort of thing went on for a while. Finally the fabricator announced that he had tried everything and that the tanks still leaked. He was asked if welding the joints had been tried. It had not been tried. One tank was welded and stopped leaking. Then the other four were welded and they have not leaked since.

In the meantime, it became necessary to substitute for two steel columns in the General Motors Building, some much smaller and more compact cast iron units in the bowling alleys located in the

basement. These columns supported only the first floor. After the first floor was shored, a local welding company burned off the two steel columns and chipped the cuts reasonably smooth. (Fig. 10.) This done, the cast iron columns were put in place. The cap of the cast iron column was provided with a steel plate bolted to the cap. The remaining section of the steel columns were then arc-welded to the steel plate and the shoring removed. (Fig. 11.)

You will observe that the experiences related up to this time did not require great strength in the weld. Gradually additional habit of thinking in terms of welding was also well fixed in my mind.

We now began to construct a large technical laboratory near Detroit, which had some unusual problems and some very large information had been obtained and confidence was increasing. The reinforced concrete members. Owing to the peculiar requirements some of the concrete girders had to be provided with an ab-

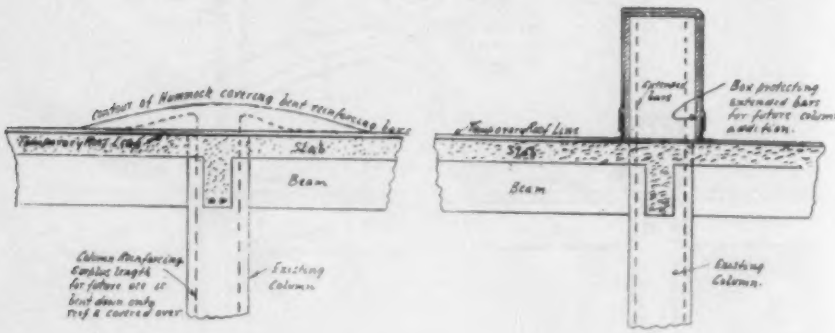


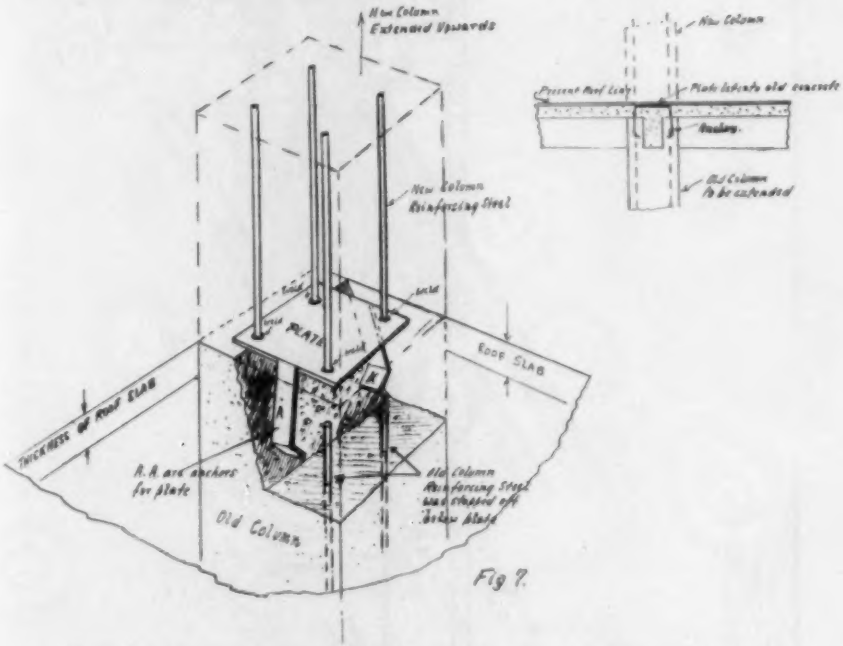
Fig 6.

Providing for future extension in buildings

normal quantity of shear bars and it became apparent that if such bars were to be placed in addition to the regular top and bottom reinforcing bars, and if these shear bars were to be given a top and bottom lap for anchorage, as is usually done, there would hardly be room left to pour the concrete into the forms. It was apparent that the top and bottom laps had to be eliminated. This could be done readily by welding the ends of the diagonal shear bars between pairs of top and bottom bars. (Fig. 12.) A small number of tests of such an arrangement were made. For testing purposes the bars were placed vertically between short top and bottom bars, in pairs. (Fig. 13.) The welds were much overdone, so there was no great danger of breaks at the joints. The tests gave more satisfaction as far as the welds were concerned than they did on the value of the bars themselves. Some of these, which should have had a minimum breaking capacity of 70,000 lb. per square inch, broke in the middle of the bar (that is, not near the welds) at about 40,000 lb. per square inch. The welded design

was, therefore, adopted. For the first time I heard the word *COST* mentioned in connection with welding. The general contractor advised that the cost of the proposed welding was too high and asked for permission to get bids on the work. He eventually got a satisfactory figure. The successful bidder made a few tests, which were also very good and the work was executed as planned.

Subsequently my attention was drawn to some welding which was being done under the direction of one of the leading firms of architects in Detroit, for the purpose of attaching seats on the existing columns of a department store. The seats were to receive and support the floor beams of an extension to the store. As I



Showing method of extending column construction in a concrete building

remember it, there were six stories at which these seats were provided. The Department of Buildings, then headed by Frank Burton, himself an excellent metallurgist and chemist, had made tests and been satisfied to allow that construction, which proved quite satisfactory.

It was but a short time after this that I was asked by one of the local welding companies to allow the substitution of welding for the usual riveting in connecting an extension of the People's Outfitting Company's building to the original structure, both twelve stories high. This involved 103 connections with figured reactions up to 26,000 lb. The point which made the welding preferable in this case as well as in the case of the department store mentioned before, was that it was possible by this method to attach the frame

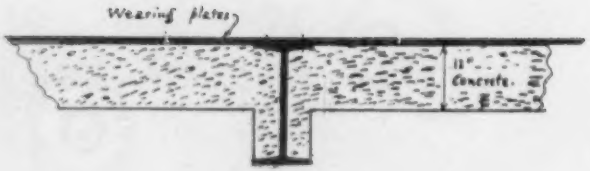


Fig 8.

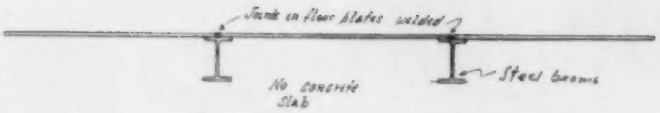


Fig 9.

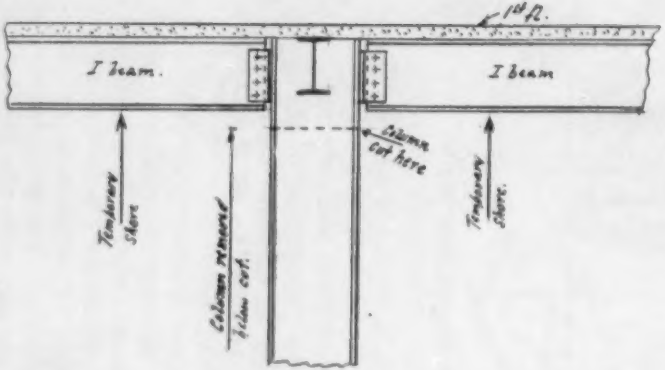


Fig 10.

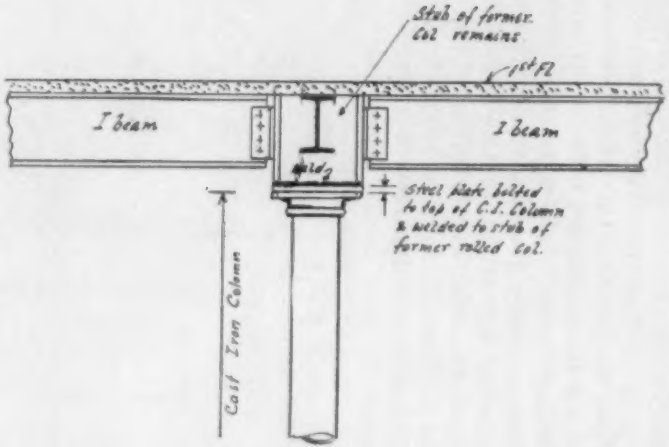

Stub of former Col remains
1st Fl
I beam
I beam
weld
Steel Plate bolted to top of C.I. Column & welded to stub of former rolled col.
Cast Iron Column

Fig 11.

Welded floor and column construction

of the extension to the existing columns without removing the exterior wall of the original building, thus permitting the owner to go on with his business without interruption until the extension was ready for use. Of course the substitution was allowed. The Department of Buildings required a sample connection prepared

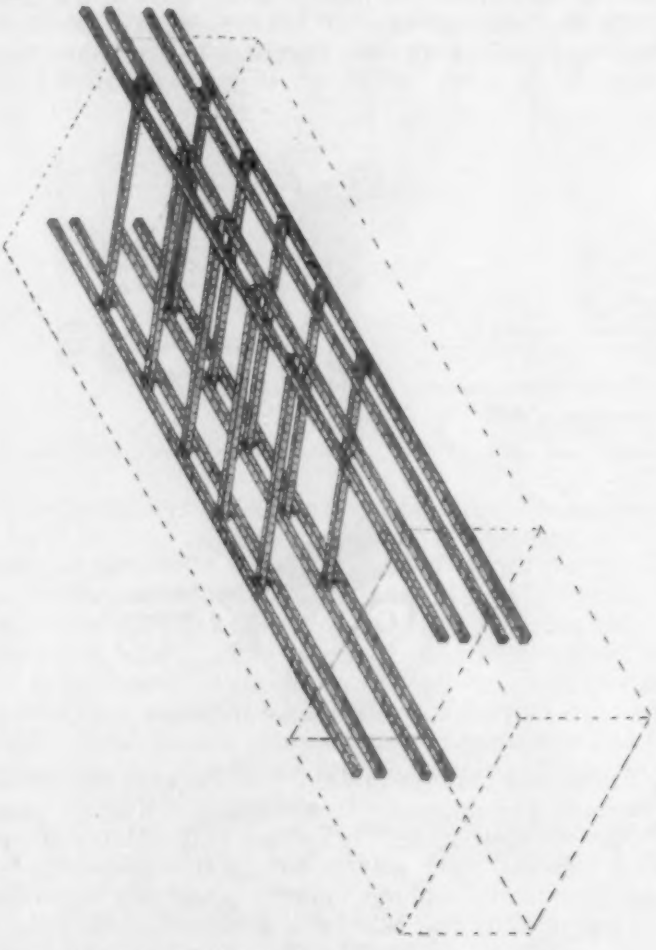


Fig. 12. Welding assists in providing shear bars

and tested it. Permission was then granted to proceed with the work. The connections were made by means of pairs of 4 x ½-in. web plates welded to the web of the beam and to the face of the existing columns. (Fig. 14.) The cost of welding turned out to be $500 more than that of riveting the two buildings together. However, the owner was not interrupted in carrying on his business.

It was now quite apparent that welding was trustworthy, had many uses in the building field, that at times it saved money, while at other times it cost more than riveting, but permitted obtaining certain advantages which more than offset the extra cost.

I began to think in terms of jobs involving much greater quantities of welding, or, if you will, jobs having a greater "footage." The first one that presented itself was the floor of an open hearth mill. This floor had an area of 120,000 sq. ft. In checking the specifications I noticed that the floor was to be riveted to the sup-

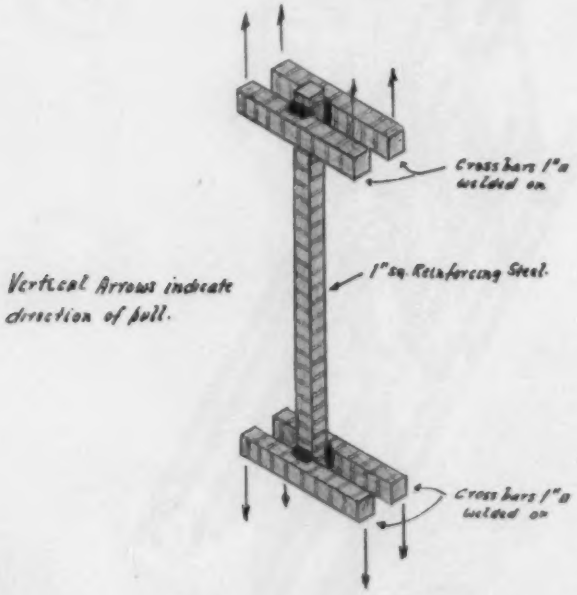


Fig. 13. Testing welded shear bars

porting beams and that for one-third of the area the rivets had to be countersunk and chipped. It was specified that the plates must be well fitted to each other. It seemed that welding the plates to the beams was the right way to handle this proposition, just as had been done in the jobbing foundry previously mentioned. Of course it was obvious that there was a characteristic difference between the two cases: the jobbing foundry floor was open to the sky while the floor in the open hearth mill was roofed over; therefore, the question of leakage did not exist.

I consulted with the representative of a large manufacturer of welding equipment. After looking over the plans he assured me that the welding proposition was feasible and would surely be cheaper than the riveted one. An alternate was therefore specified. Shortly afterward I was advised that there was something akin to a panic among the local welders. The amount of welding involved was 43,000 lin. feet. It was stated that there was not

enough equipment nor enough welders locally to handle the job in three months. Only one bid had been received on the welding alternate; it was from a very large fabricating company of national importance offering to weld the job at the same price as quoted by them for countersinking, riveting, chipping and caulking. The low bidder did not quote on the welded alternate. His price was $8 per ton less than that of the fabricating company alluded to. The low bidder stated that the best welding price that had been proposed to them was about twice that which they had figured for doing the job in the usual way. At this point the representative

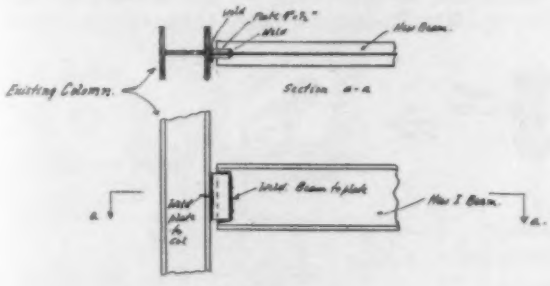


Fig 14.
Welding new extension to existing building

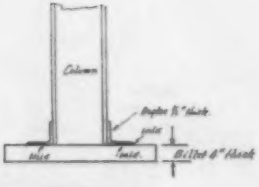


Fig. 15.
Welding column to base

of the manufacturer of welding equipment alluded to before, walked in and aptly pointed out that the welding alternate was not fair because while the rivets were spaced 6 in. apart the welding was expected to be continuous. There was no reason for continuous welding in this case; it was only a matter of securing the plates to the supporting beams. The alternate was immediately modified to make it fair, and as in the meantime the steel contract had been let, the steel contractor himself got prices on the revised arrangement. Even then it proved to be too expensive and too slow and the job was put in with its full complement of countersinking, riveting, chipping and caulking.

Thinking this case over, I observed a new factor, one that had not hitherto appeared very important: slow progress in welding with the means at hand. Slow progress meant a high rate per foot and that rate had killed the welding alternate.

At about the same time it was planned to construct a one-story exhibition building, which consisted of several parallel aisles, each aisle having a continuous arched shape skylight. A fabricator located in northern Ohio noted in his tender that if the foot of the arches was allowed to be welded instead of riveted, he would lower his price $2,000. The job, however, went to another firm whose price was $10 per ton less than the Ohio fabricator.

Sometime later, in connection with the construction of a club building in Chicago, it was desired to build on the sixth floor a swimming tank of approximately standard dimensions. Having

clearly in mind the results described above in connection with the open hearth mill, I thought over carefully the scheme of putting in a tank made up of welded plates and channels rather than one made up of riveted plates and shapes. Going back mentally over my previous experiences, I came to a conclusion which I firmly believe to be correct at present and which might be enunciated as follows:

"In the present state of the art field welding is more expensive than riveting unless some advantage resides inherently in the welding which offsets or overbalances the extra cost."

Keeping this "principle" in mind I studied the swimming tank carefully and made up my mind that there was "an advantage residing inherently in the welding": which was that if the tank

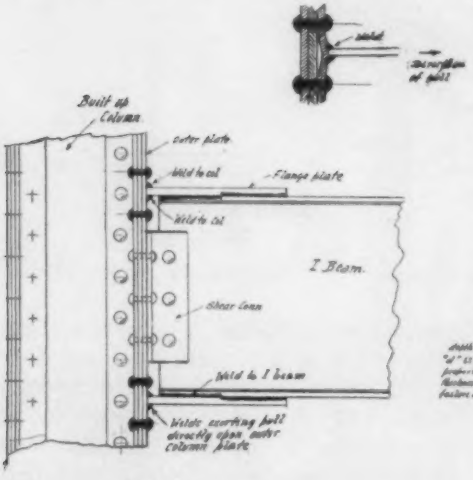


Fig 16.

Welding beams to built-up columns

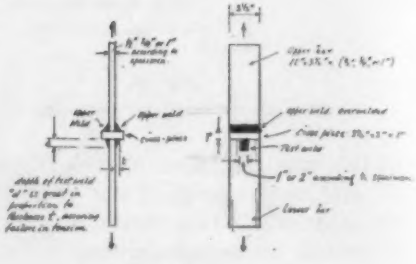


Fig 17.

Tension test specimens

were riveted and caulked a waterproof felt must be used, while if it were welded, no such felt would be required. The tank was consequently designed as a welded job, without a single bolt or rivet hole. The intakes and drain box were designed to be welded to the tank proper. This was a neat job and I was satisfied that we would have no trouble with the cost of it nor with its behavior. After the general contract was let I was called from Chicago and told that the cost of the tank was running away high compared to a riveted job. I was quite surprised. A pertinent question brought out the fact that the contractor had not noticed that the waterproofing felt was to be omitted if the tank were welded. This deduction plus a last bid which was better than the others, settled the argument; the tank was welded and has given satisfaction since. A description of the work appeared in *The Welding Engineer* for September, 1925, and also in *Engineering News-Record* for March 4, 1926.

Recently an extension made to the Detroit Trust Company pre-

sented the condition before mentioned, of keeping the existing structure intact so as not to interfere with the conduct of business. Of course, the two structures were welded together. Some girders carried a figured reaction of 225,000 lb.

Last year the Chevrolet Motor Car Company extended one of its buildings at Janesville, Wis. We had again the now familiar problem of attaching the new unit to the existing structure. The two units were welded to each other.

Just now an extension is being made to the First National Bank Building. Both the existing structure and the addition are twenty-five stories high. The same requirement of keeping the existing building closed until the new building is finished as well as the

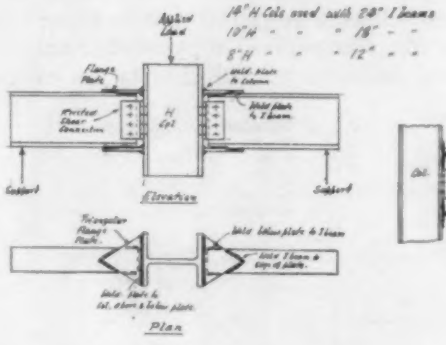


Fig 18.

Wind bracing test specimen

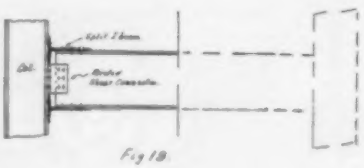


Fig 19.

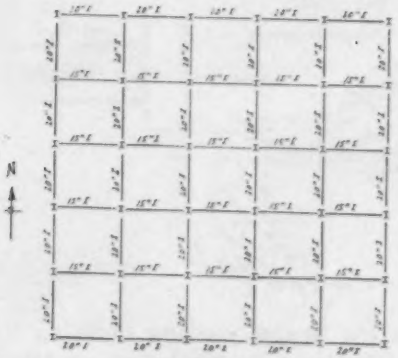
Riveted bracing

avoidance of vibration to the existing building by riveting caused the plans and specifications to be drawn on the basis of welding the two units to each other. Contracts were recently let for this work.

In connection with the First National Bank Building, the proposed welding program was planned on a more ambitious scale. All the wind bracing was designed as field welded, with an alternate allowing steel contractors to tender on riveted work if they desired. About four years ago I undertook to find some way out of the laborious details in vogue at the time for such bracing. It occurred to me eventually that a solution might be found by introducing welding. The plan was to prepare simple details which could be executed by the welding contractor following directly behind the steel erector and to relieve the steel contractor of the fabrication and erection of complicated details which were never to his liking, giving him a simple and straightforward beam and column job.

It was the intention to assist the steel contractor by the judicious introduction of welding. The beams were to be riveted to the columns to carry the usual live and dead loads, and the wind-bending stresses were to be resisted by welded connections. R. G.

Richards, sales manager of the Slaymaker Welding Company, promptly set about making all the arrangements required. Several meetings were arranged for and held between representatives of the principal local welding companies, the steel fabricators, the leading architectural and engineering firms, the Department of Buildings and Safety Engineering, and representatives of the welding supply companies. These meetings brought out many interesting facts. The steel companies were quite agreeable to the idea of substituting welded wind connections if they were economical and provided that matters could be arranged to prevent division of responsibility and confusion on the job. They also agreed to furnish and fabricate whatever test specimens might be required, thereby proving their willingness to cooperate. The welding companies agreed to do all the test welding required and to absorb the test costs. The welding supply companies' representatives furnished all needed information relative to suitable types of ma-

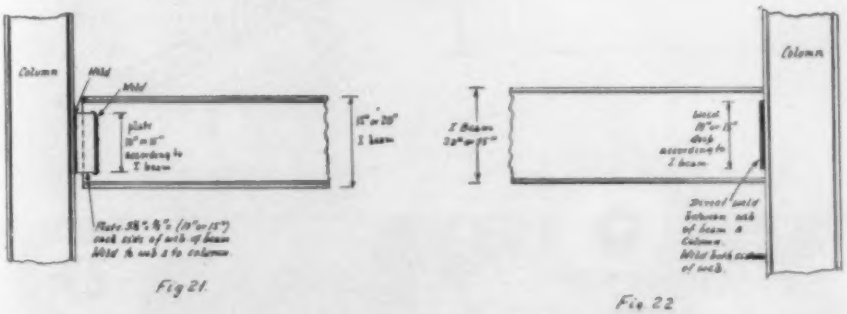


FRAMING PLAN

FIG 20.

chines, availability of equipment and many details regarding the proper handling of the work and of the equipment itself. The structural engineers immediately set about discussing the kind of tests which should be made as well as the general subject of arc-welding of buildings. A number of pertinent points were brought up. A question was raised as to possible methods of checking the soundness of a weld after it is made, just as the soundness of a rivet is checked, it being remarked that even a loose rivet still provided a shaft of metal through the holes to secure the members to each other, while a defective weld had no corresponding value. The difference of strength claimed for various types of welding wire, which naturally influences the design of connections, came in for its share of attention. One engineer observed that tests he had made indicated that if two pieces of metal of different temperature were welded together there resulted an initial stress of 195 lb. per square inch in the weld metal itself for each degree difference of temperature between the two pieces. This statement must be taken

for what it may be worth, but it seemed to account for the difficulty of making a good weld between angles ½ in. thick and column billets 4 in. thick; it had been noted that the angles could readily be knocked off by striking them with a hammer. (Fig. 15.) It was pointed out that the idea of connecting beams to columns by top and bottom plates to resist end moments or end bending, as for wind bracing or for continuous action could not be used if the columns had cover plates, as the weld would adhere to the outermost plate only (Fig. 16) and that it would require more riveting to tie all plates together than there was space available. It was thought that such welds could only be applied to solid rolled sections, but that fortunately for the welder, the day of the built-up column sections was nearing twilight.



Welded beams to columns

The necessity for more intimate technical knowledge of welding by the structural engineer, before welding was generally taken up by him, was spoken of. It was observed that he would require not only information regarding test values and strength of welds, but also training to be able to inspect the work intelligently. An objection was made to the general use of welding for structural work on the ground that it required much experience to do it properly, that is to avoid burned contact surfaces, warped members, welds of unequal strength per lineal inch, etc., and that very few welders had obtained the requisite experience. It was aptly remarked that since steel is a material made by the fusion of various materials, its composition cannot posssibly be perfectly uniform and that consequently even if a perfect welding wire could be obtained, one which had always the same identical strength when it was used to unite two bodies of variable composition, the ideal welding material could not adhere uniformly to them, that it must get a firmer purchase at some points than at others. Under such conditions it was expected that tests under given conditions would vary considerably in strength. Some of the engineers present had not had much opportunity to get well acquainted with welding, but all had given the subject careful thought and this was clearly shown by their observation.

It was agreed that the first requisite was to make some tension tests. I was once told that there had been so many tests made on welded specimens that further testing was not necessary. According to that, all we had to do was to read about the tension tests made elsewhere and that would supply us all the information required. It must be said, however, that it would not tell us just what values we could expect from the local welders using the equipment and wire they are accustomed to, nor would it provide a demonstration of proper merit to pass the requirements of the De-

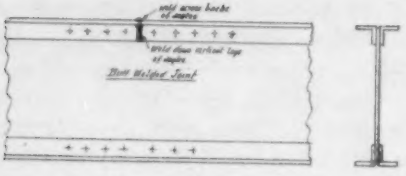


Fig 23

Welding butting chord members

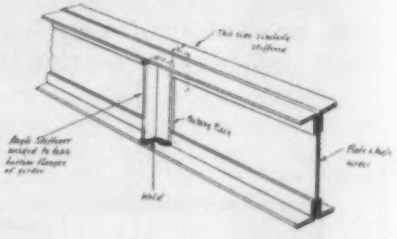


Fig 24

Stiffeners welded to chord members

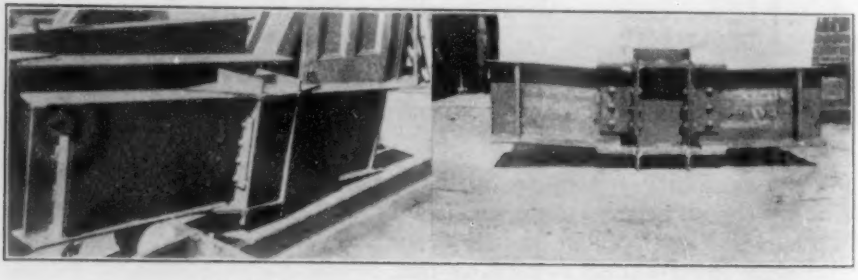


Fig. 25. Test specimens of welded wind bracing

partment of Buildings. A number of schemes were proposed but none was found for some time which gave purely tension results and which could be held in the grips of the testing machine. Eventually Mr. Slaymaker designed a test specimen which proved very satisfactory. It consisted of two bars 3½ in. wide and 12 in. long welded to a cross piece 2 x 3½ x 1 in. thick. (Fig. 17.) The upper bar was overwelded to the cross piece so as to eliminate the possibility of breakage there. The weld on the lower bar was made exactly 1 in. or 2 in. wide, depending on the specimen and the thickness of the weld on the cross piece was made by welding up to a scratch mark, insuring substantially the exact thickness specified. The depth of weld on the lower bar was also overdone so that the joint was bound to break by weld tension, and not by shear, the lower bar pulling away from the cross piece. Twenty specimens of this kind were prepared and tested by the Perry Testing Laboratory. (Table 1.)

It was observed that the wire used on the specimens giving the higher tension values was of a radically different make than that used on the other specimens. It was thought wise to have a few samples made by the welders who had produced the samples giving the lower values, using this time the type of wire which had produced the higher tension values. This particular wire could not be obtained when needed, but another one by the same manufacturer was used after it had been explained that it was a wire of greater strength than the one previously used. At the same time some specimens were prepared on an alternating current machine to see how its results would compare with the direct current welds used in all the other tests. (Table 2.)

Table 1

Ultimate Load, Lb.	Area of Weld, Sq. In.	Stress on Weld, Lb. per Sq. In.	Type of Wire	Current	Welded by
25,150	0.546	46,062	Wilson CoatedNo. 10	D.C.	Shop 1
33,640	0.593	56,729	Armco Bare	D.C.	Shop 2
39,930	0.557	71,752	Wilson Coated No. 10	D.C.	Shop 1
63,180	1.016	62,209	Wilson Coated No. 10	D.C.	Shop 1
44,220	0.705	62,732	Wilson Coated No. 10	D.C.	Shop 1
73,610	1.230	59,826	Wilson Coated No. 10	D.C.	Shop 1
50,150	0.866	57,903	Wilson Coated No. 10	D.C.	Shop 1
88,050	1.766	49,869	Wilson Coated No. 10	D.C.	Shop 1
24,750	0.562	44,007	Armco Bare	D.C.	Shop 2
47,850	1.348	35,511	Armco Bare	D.C.	Shop 2
39,650	0.805	49,230	Armco Bare	D.C.	Shop 2
75,810	1.437	52,741	Armco Bare	D.C.	Shop 2
38,790	0.866	44,792	Armco Bare	D.C.	Shop 2
75,200	1.547	48,616	Armco Bare	D.C.	Shop 2
32,070	0.645	49,759	Roebling Bare	D.C.	Shop 3
65,800	1.484	44,331	Roebling Bare	D.C.	Shop 3
43,530	1.047	41,587	Roebling Bare	D.C.	Shop 3
67,730	1.435	47,188	Roebling Bare	D.C.	Shop 3
48,510	1.219	39,804	Roebling Bare	D.C.	Shop 3
105,650	2.156	48,998	Roebling Bare	D.C.	Shop 3

By this time we had secured a good deal of first-hand information and we had some designing data available. I feel very sure that structural engineers will do well to make some tests of their own in their individual locality. Not only does it give them information which takes account of local conditions but it puts them in a position to read much more understandingly the reports of tests made by others elsewhere. It makes an engineer much more willing to place faith in these other results as he is in a position to understand them so much more clearly.

The next step was to make full size wind bracing connections and to test them. In designing these the testing machine clearances had to be taken into consideration. Several designs were made which were very good in themselves, but which could not be accommodated in the machine. It was finally decided to use a section of H column and to attach a cantilever beam on each side by a standard web connection riveted to both the beam web and to the

column flange. (Fig. 18). This connection was the identical one which would be used on a building in connecting columns to beams of the sizes used. The relative size of beams and columns was also selected to approximate what would be found in a building, the small beams being secured to light columns and the large beams to heavy column sections. This riveting was done by the steel fabricators. The samples were then taken to the various welding shops. Here, triangular plates were provided connecting the top and bottom flanges of the beams to the column faces. All work which would have to be done overhead in the field was done overhead in the shop. Twenty-seven such samples were made up and brought to the laboratory for testing. (Table 3.)

Table 2

Ultimate Load, Lb.	Area of Weld, Sq. In.	Stress on Weld, Lb. per Sq. In.	Type of Wire	Current	Welded by
17,280	0.281	Shear Failure	Wilson Coated No. 10	A.C.	Shop 1
49,920	0.516	Shear Failure	Wilson Coated No. 10	A.C.	Shop 1
44,780	0.899	49,800	Wilson Coated No. 10	A.C.	Shop 1
73,230	1.594	45,950	Wilson Coated No. 10	A.C.	Shop 1
51,140	1.094	Shear Failure	Wilson Coated No. 10	A.C.	Shop 1
98,110	2.125	Shear Failure	Wilson Coated No. 10	A.C.	Shop 1
37,360	0.810	46,112	Wilson Coated No. 17	D.C.	Shop 2
69,300	1.551	44,692	Wilson Coated No. 17	D.C.	Shop 2
45,270	0.844	53,688	Wilson Coated No. 17	D.C.	Shop 2
67,900	1.584	42,860	Wilson Coated No. 17	D.C.	Shop 2
95,100	2.281	41,688	Wilson Coated No. 17	D.C.	Shop 2
40,920	0.703	58,199	Wilson Coated No. 17	D.C.	Shop 3
66,950	1.328	50,414	Wilson Coated No. 17	D.C.	Shop 3
41,900	1.102	37,948	Wilson Coated No. 17	D.C.	Shop 3
92,340	1.953	47,283	Wilson Coated No. 17	D.C.	Shop 3
50,000	1.076	46,468	Wilson Coated No. 17	D.C.	Shop 3
96,610	2.000	48,305	Wilson Coated No. 17	D.C.	Shop 3

I am making no comments on the test results, but they are worth while studying carefully.

At various times during these proceedings the question of probable cost of welding wind bracing had been discussed. It seemed the consensus of opinion that a contract price ranging somewhere between $1 and $1.50 per lineal foot would be quoted. Many estimates of the type of connections tested and of some others were made and estimated sometimes at $1.25 per lineal foot and sometimes at $1.50 per foot. In all cases the welded bracing showed a substantial saving over the corresponding riveted work. The most effective riveted bracing connection consists of a heavy T obtained by cutting in two a large I beam perhaps 12 in. or 14 in. long and using each half as a connection for the beam flanges to the column. (Fig. 19.) This is also an economical connection. But even this connection was found to be more expensive than the welded plate connection tested at the laboratory, using the unit prices mentioned. It, therefore, was logical to design the bracing of the next large building on the basis of welded connections after securing the approval of the Department of Buildings.

This next building was the First National Bank extension already referred to. When the welding companies bids were received it turned out that the figures quoted ran around $2 per lineal foot for the 6500 lin. ft. of welding involved. The low bidder on the structural steel work quoted $7,500 less for riveted than for welded bracing. I may say that the next structural steel bid in line quoted $8,000 more for riveted than for welded bracing. It is to be observed, however, that in a contract involving in the neighborhood of a half million dollars, many owners and some engineers would not consider it particularly wise to adopt a new style of construction to save $8,000 when there might happen some delays or other

Table 3

Test Number	Tension on Weld, Lb.	Area of Weld, Sq. In.	Stress on Weld, Lb. per Sq. In.	Remarks
1	243,500	14.5	16,800	Weld failed at column.
2	291,000	14.5	20,000	Weld failed at column.
3	355,000	14.5	24,500	No weld failure.
4	337,500	14.5	23,250	No weld failure.
5	325,000	14.5	22,400	No weld failure.
6	356,000	14.5	24,500	No weld failure.
7	348,000	14.5	24,000	No weld failure.
8	159,000	14.5	11,000	Weld failed at column.
9	240,000	14.5	16,550	Weld failed at column.
10	182,600	10.25	17,800	Weld failed at column.
11	219,000	10.25	21,350	Weld failed at beam.
12	168,000	10.25	16,400	Weld failed at column.
13	223,000	10.25	22,700	No weld failure.
14	214,000	10.25	20,850	Weld failed at column.
15	235,000	10.25	22,900	No weld failure.
16	225,000	10.25	21,950	Weld failed at column.
17	209,000	10.25	20,350	Weld failed at column.
18	131,000	10.25	12,800	Weld failed at column.
19	113,500	6.75	16,800	Weld failed at column.
20	119,000	6.75	17,650	Weld failed at column.
21	132,000	6.75	19,500	Weld failed at beam.
22	135,000	6.75	20,000	Weld failed at beam.
23	142,000	6.75	21,000	Weld failed at beam.
24	106,600	6.75	15,700	Weld failed at beam.
25	146,000	6.75	21,600	Weld failed at column.
26	151,000	6.75	22,400	Weld failed at column.
27	137,500	6.75	20,350	Weld failed at beam.

occurrences which would make them lose more than the proposed saving. One point of interest relative to taking off the quantity of work required for the building just mentioned was that the welding companies employed the services of a quantity surveyor to establish the amount of work involved. The quantity surveyor and I compared estimates which agreed very closely. Thus all welding companies figured on identically the same basis and were relieved of the estimating.

There have been a number of other excellent examples of structural welding in this vicinity which have come under my observation, such as the coal bunkers of the Trenton plant of the Detroit Edison Company, the new all-welded building of the Barnes Wire Fence Company and a proposed method of reinforcing the existing

columns of a structure to which many additional stories are being added, by welding on reinforcing cover plates; but I have purposely limited myself to personal experiences.

As matters now stand, I can use welding any time occasions recur in which welding has already been used successfully, as already described. But when called upon to proceed farther, to go ahead and to extend the use of welding on a broader scale, I am confronted with the so-called "principle" that I formulated before. I am aware that it has been found possible to weld complete buildings in Canton, Pittsburgh, Detroit and that one will be started shortly in Philadelphia. Some very sanguine claims have been made at times. It may be pertinent to give a specific comparative cost and time analysis. I have in mind a multiple story building 100 ft. square which is now nearing completion in Detroit. The steel work went up at the rate of substantially five stories per week. (Fig. 20). To simplify matters, we will assume that the framing plan consists only of beams framing directly to the columns, omitting beams around stair wells, elevators, pipe shafts and leaving out of consideration all wind-bracing connections, mullion ties, spandrel and pier shelf angles. All wall beams are 20 in. — 65 lb. I beams. All interior north and south beams are 20 in.—65 lb. I beams. All interior east and west beams are 15 in.—42 lb. I beams. The average weight of all columns is 300 lb. per lineal foot.

Let us first consider the cost of erection as a riveted proposition:

The beam tonnage per floor is		69,500 lb.	
Add 5% for connections		3,500 lb.	
		73,000 lb.	
The column tonnage per story is	103,000 lb.		
Add 10% for details	10,000 lb.		
		113,000 lb.	
		186,000 lb.	= 93 tons

For five stories we have a total of 465 tons. The cost of erection, including trucking, handling, hoisting, setting, plumbing and riveting is $15 per ton. The cost is then $6,975.

Let us now consider the cost of erection as a welded proposition. (Fig. 21). All beams to be welded to columns by means of pairs of 3 x ½ web plates at one end and directly to column, without web plates, at the other, the height (Fig. 22) of weld being 15 in. on the 20-in. beams and 10-in. on the 15-in. beams, so as to obtain about the same rigidity as riveted construction gives. The column sections will be welded directly end to end without splice plates. In each story we find 460 ft. of welding for beams. Five stories give us a total of 2700 lin. ft. Assuming the columns to be H shape and 15 in. square, we find 7 ft. of welding per splice. There are 2½ splices in five stories or a total of 630 ft. of column welding. The total welding in five stories is then 3330 lin. ft. and this at $2 per foot amounts to $6,660.

In addition, we have to allow $10 per ton for trucking, handling, hoisting, placing and plumbing. The tonnage is 430 tons, 35 tons of riveting details having dropped out. This 430 tons at $10 per ton adds $4,300 to the welding cost. The 3 x ½ plates amount to about $200. The total cost is then $11,160.

Comparing only the cost of riveting and that of welding, that is, leaving out the handling, hoisting, etc., we have for riveted work 465 tons at $5 or $2,325, and for welded work 3330 ft. at $2 equals $6,660 plus $200 for the 3 x ½ plates or $6,860. This is a case in which no "advantage resides inherently in the welding which offsets or overbalances the extra cost."

I quite appreciate the fact that at present welding equipment is called on for the most diverse uses. Today it is used to weld some vehicle frames; tomorrow to repair a broken machine, a leaky boiler or to secure piping. In the middle of these activities comes the spasmodic call of the structural engineer for assistance in some of his perplexities. I am not concerned, of course, with organized lines of work in certain manufacturing establishments where welding is a regular part of the program. If structural welding could at present be handled in that same fashion it would naturally cost much less. As matters stand it is necessary to charge against a large structural job all equipment which it is found necessary to add to that on hand. The newness and uncertainties of the venture require caution so that proper organization is very expensive.

Some new method of cooperation between the welders and the welding supply companies may eventually be worked out, resulting in a material cost reduction. The present situation is rather similar to that which existed in the early days of the stamping business; if the whole cost of stamping equipment had always been charged to the first article produced the volume of sales would have been nil and the industry would not have developed.

It seems to me that the present type of equipment is too slow for large structural enterprises. Consider the example of the multiple story building already mentioned. As it is impractical to walk around on a steel frame after dark not more than two shifts could be counted on, or 16 hours a day, or 96 hours per week. The rate of welding considered practical on that type of work has been estimated to be from 3 to 4 ft. per hour, which would mean about 1000 hours for the work described. That requires about 10 machines to do the job in the time which was actually taken. Now, if all the work which was left out to make the comparison simple, such as secondary framing, wind bracing, shelf angles, etc., is added in, it more than doubles the quantity of welding which would be needed. Thus we see that more than twenty machines would have been required working 16 hours a day to perform the work in the same time in which it was actually accomplished.

For the present, structural engineers will feel inclined to favor rather long and heavy beads on account of the wide variation in the strength of test specimens. This will require that extra speed be provided to complete the work in the time required.

Nevertheless, the portability and flexibility of this same equipment are among its best features. In a structural steel shop there are frequent cases in which the welding equipment is of value. There are some details which can be simplified there by the substitution of welding for the established methods. For instance, in a long truss or girder the compression chords being spliced (Fig. 23) it is obvious that butting chord members together and welding them is a simpler process than to put in splice plates and angles and to supply enough rivets on each side of the splice to take the whole calculated compression. Stiffeners on girders may be cut to a fairly close fit and welded to the chords (Fig. 24), so that both legs of the stiffener can be counted on in bearing to carry the load or reaction instead of only the outstanding leg as is frequently required. It is clear that in some of the more unusual or complicated structures, such as hip-roofs, a good deal of drawing, shop-work and even field work can be simplified or entirely avoided by using welding equipment.

It is manifest that much progress has been made in the applications of welding to structural problems and I firmly believe that as developments take place the number of possible applications is going to increase steadily. To take advantage of favorable conditions it is going to be increasingly necessary not only for the structural engineer to understand welding but for the welding engineer to be thoroughly familiar with construction work. Many a time in past years have I been told by welding company representatives: "I am not a structural man; I am not familiar with your problems so I cannot advise you properly; you will have to tell us what you want." I have before me a circular letter from a leading welding supply manufacturer in which I read that one thing they will not do for us is to design the structure because that is our job. It *is* our job to design the structure: to design it in the usual orthodox way. There is no reason why we should undertake to design it in some other fashion unless we are shown that it is advantageous to do so. It is the province of the welder to come and show us where, when and how welding is advantageous; obviously this requires that he be a thoroughly experienced construction man, that he know in detail the problems involved so that when he has found a better solution for them he can explain it in terms that we understand.

I have outlined the experiences in structural welding of a constructing engineer. Even as matters now stand the immediate opportunities include all these experiences multiplied by the number of busy architectural, engineering and construction firms throughout this country. We are steadily making progress in every direction and we are going to face countless new problems as we advance. We are going to solve these problems; we are going to conquer every difficulty and I know that very frequently the credit will be due to The Welding Engineer.

be provided to complete the work in the time required.

Some Metallurgical Observations on Welding*

G. R. BROPHY†

Enough importance has not been attached to the metallurgical aspects of welding and the choice of materials used. The quality of the steel welded has such a marked influence upon the properties of the weld that more rigid specifications should be drawn for the steel used in fabricating new structures. For instance, a standard tensile test bar machined entirely from deposited metal had the following tensile properties:

Tensile strength	61,300 lb.
Yield point	44,100 lb.
Elongation 2 in.	24 per cent
Red. area	35 per cent

This metal certainly is strong and ductile. A test bar machined from the bead of two ¾-in. plates jointed by welding with the same wire as used before gave the following properties:

Tensile strength	49,000 lb.
Yield point	35,600 lb.
Elongation	11 per cent
Reduction of area	15 per cent

This indicates that a good deposited metal is being contaminated by a poor quality of plate stock.

Time as a factor in welding is as important as in the heat treatment of steel. Melting, freezing, solution precipitation, and purification of metal all require time, and unless time is allowed these processes do not go to completion. The improvement of the properties of a weld by annealing is due to the fact that additional time is allowed for reactions to proceed which had been stopped by the rapid cooling of the weld. The purification of the molten deposit by slag is rather doubtful because of the lack of time and for the same reason the slag is not eliminated from the weld.

The rate of deposition, the current and voltage used, and the size of the electrode as related to the section of metal being welded are also important factors in the production of better welds.

The analysis of electrode (other than alloy wires) as far as the effect on the analysis of the deposit, is of no great importance, as has been shown by Rawdon.[1] The carbon, silicon, and manganese, phosphorus and sulphur of the electrode is reduced by passing through the arc to nearly the same amount whether the electrode was high or low in these impurities.

Bare Electrodes

It is generally recognized that the so-called cored electrode is most satisfactory considering arc stability and general smooth-

*To be presented at the Annual Fall Meeting of the A. W. S., Sept. 21, 1927.
†Research Laboratory, General Electric Company.
[1] Bureau of Standards Tech. Paper No. 179.

ness. Various reasons have been assigned to the causes of this coring. Guthrie (A.S.S.T., March, 1927) gives the most plausible reasons for coring in carbon steels. This he attributes, and correctly, to a difference in condition of the carbide. That in the core occurs in pearlite while in the rim it is in the spheroidal or free state. These two conditions cause differences in solubility so that upon etching the metal of the core is attacked more rapidly and appears dark. This also explains why some investigators have been led to believe that coring is caused by sulphur segregation.

These two forms of the carbide will in all probability cause differences in melting rates of the core and rim, because more time is required to dissolve the spheroidal carbide than the pearlite

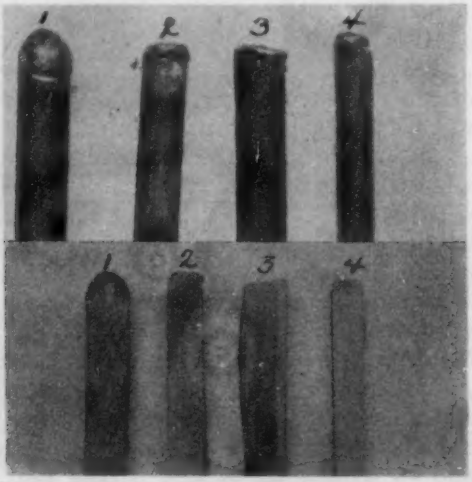


Fig. 1. Electrode tips
No. 1. High carbon steel.
No. 2. .20 carbon.
No. 3. High carbon core, low carbon rim.
No. 4. Composite core, low carbon rim.

carbide, and therefore the rim has a slower melting rate than the core. If more time were allowed for melting this would not be true.

Another reason for coring is an actual difference in carbon content in rim and core. This obviously will cause the core to melt at a lower temperature because of its higher carbon content.

Still another cause for coring, in the case of the pure iron type of wires, is the difference in slag content of the core and rim. The core is usually higher in slag than the rim, and while the melting points of the core metal and the rim metal are the same the melting rates will certainly be different. Again the core metal will be removed more rapidly.

To demonstrate these conditions wires were made to correspond to the above structures. A rimmed wire of about .20 C was used for the first case. A high carbon wire, drawn down inside a low

C tube, was used for the second, and a mixture of powdered iron and slag were drawn down inside a seamless tube for the third condition. These wires were used as electrodes and worked very smoothly, particularly in the last condition.

A study of the tips of these electrodes is very instructive. The upper group of Fig. 1 shows the fused ends. The lower group shows these same ends split. Number 1 is a 1 per cent carbon steel of uniform structure and shows a large bubble containing gas holes. This wire, as is well known, drips badly and does not arc at all well. No. 2 is the rimmed .20 C steel which shows a flat tip. This wire works fairly well, but can not be considered at all smooth. No. 3 is the high carbon core with the low C sheath. A decided concave tip is formed and considering the high C of

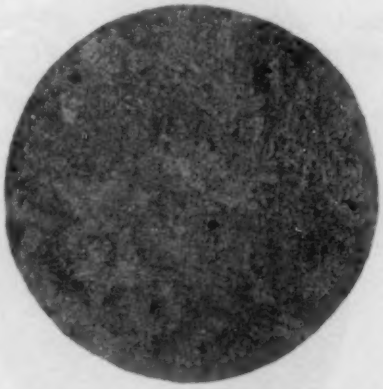


Fig. 2. × 75. Deposit from heavily coated electrode. Slag inclusions numerous

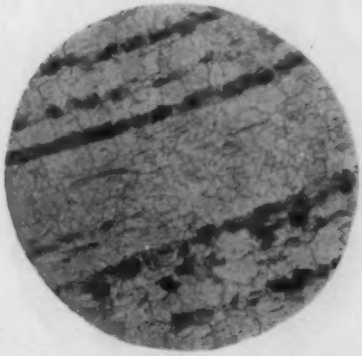


Fig. 3. × 75. Laminated plate stock

the core the electrode is a good one. No. 4 is the composite core with the low carbon sheath. In spite of the fact that the pure iron of the core is actually a higher melting metal than the sheath, the core is removed much more rapidly than the sheath, as is shown by the hole in the end of the tip. This electrode arcs quietly and smoothly and gives a very sound bead.

From these experiments and observations the conclusion may be drawn that a cored condition of the electrode leads to differential melting, i.e., the core melts or at least is removed faster than the rim, thus giving a concave tip, the projecting edges of which confine the arc and gives a quiet and smooth working electrode. This action may be termed mechanical shrouding of the arc.

Coated Electrodes

Electrodes heavily coated with various materials such as paper, asbestos, and other slag mixtures, have been in use for some time with excellent results. The arc is usually steady and quiet and the deposits of good quality.

A study of the action of these electrodes shows that the heavy

coatings act primarily as mechanical shrouds. With paper, it first carbonizes, forming a protecting tube which entirely incloses the arc stream, and holds intact to the plate where it curls and burns, giving in addition a gaseous shield which prevents contamination of the weld by oxygen and nitrogen.

The slag coatings also form protection for the arc. A layer of molten slag is formed over the deposit which to some extent prevents contamination, but to offset this, considerable slag is also trapped within the deposit. Fig. 2 is a micrograph of one of these deposits and numerous slag inclusions may be seen. These have a weakening effect.

The thin coatings, such as the usual rust coating, acts beneficially only to steady the arc, and has little effect on the deposit and certainly no good effect.

Investigations of welds for porosity shows that those deposits made from very quiet arcs are much sounder than those from the

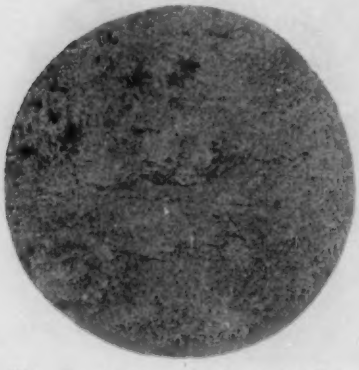


Fig. 4. × 75. Cracks extending back into plate along streaks

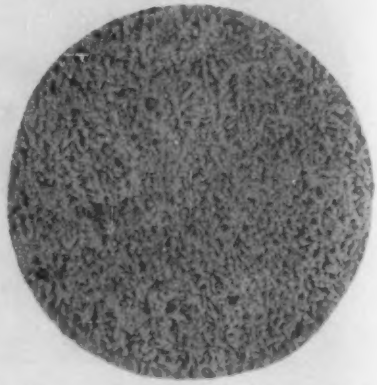


Fig. 5. × 75. 30-35 carbon plate

wild sputtering arcs, conditions of current, voltage, and rate of deposit being the same. One would suspect then that gas is mechanically inclosed by the metal when the arc is wild.

Plate Stock

A large number of samples of plate stock have been investigated and found to vary considerably in physical properties, composition, and structure. The poor quality of most is outstanding. Carbon is found to vary from .05 per cent to .5 per cent. Segregations and laminations, ghost lines, large slag inclusions and holes are found too frequently.

Figs. 3 to 6 show the conditions commonly met with in material which is called boiler plate and tank plate, and generally used for welding.

Fig. 3 ghost lines and segregated carbon and slag inclusions are shown. The carbon content of this steel is nominally 0.15 per cent to 0.20 per cent, but locally may run as high as 0.5 per cent.

This condition causes very low strength and ductility in a direction at right angles to the laminations. In some cases this transverse strength is only half of the longitudinal strength and the ductility is much less. Fig. 4 shows a condition resulting during welding from these laminations. Cracks caused by heat stresses extend back into the plate along the low carbon, high impurity zones.

Figs. 5 and 6 show a considerable difference of carbon content in plates used in the same way and for the same purpose. While of fair quality the carbon difference of 0.25 per cent is too great to obtain consistent results.

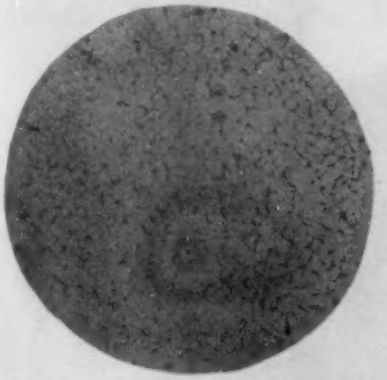


Fig. 6. × 75. 10-15 carbon plate

Fig. 7. × 75. Porous plate stock

The carbon content of the parent stock has considerable influence on the strength and ductility of the weld. Welds made on good quality .10 C steel show a strength of 25 per cent less than welds made on a .30 C steel, but of course greater softness and ductility and resistance to shock. This should be taken into consideration when comparative tests of welds are made. Higher carbon gives harder and stronger, but more brittle welds, while low carbon gives soft, ductile welds, and comparatively low strength.

Fig. 7 shows a condition commonly encountered which is believed to contribute to porosity. The hole shown, which is one of seven in an area of ⅛ sq. in., probably liberates gas through the molten metal. Some of this gas is trapped by the freezing metal, causing holes in the bead.

Fortunately, good quality steel is obtainable at little if any increase in price and when used the increase of strength and ductility and decrease of porosity more than justify any added cost of metal.

Metallographic Structure of Welds

Oxide, nitride and carbide have been described in detail on numerous occasions, so that the usual descriptions may be omitted. Their special effects will, however, be discussed.

Because of the progressive nature of the freezing of the deposited metal, the grain of the solidified metal is as a rule columnar, a condition which does not add to ductility and strength. Upon annealing, this grain may be broken up and the resulting grain be equiaxed with considerable increase in physical properties. It must be remembered that the metal is essentially a cast steel, so that annealing temperatures should be high and the annealing time long to get the best results.

At times, these columnar structures are almost impossible to break up, and this is attributed to oxide films in and around the large grains which will prevent proper annealing results, even though the individual grains do recrystallize. On the other hand, welds which solidify in some gases or under suitable slags will

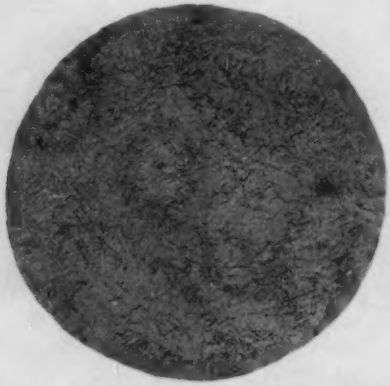


Fig. 8. × 75. Gas shielded arc. Nitride needles numerous. Deposit has high ductility

recrystallize on very short annealing, which seems to prove that oxide is the reason for persisting columnar structure.

Again, while considerable brittleness is no doubt due to nitride the chief offender is oxide. Because, with the nearly complete elimination of oxide by means of gaseous shields, even though nitride is present in considerable quantities, excellent ductility results. Micrograph No. 8 shows the structure of a gas shielded weld which bent 180 deg. without fracture. This weld contains the usual amount of nitrides as shown by the number of needles appearing.

A peculiar phenomenon which occurs with higher carbon steels under the usual conditions of welding, and is also noticed in electrode tips, is a migration of carbon from the plate stock to the zone of fusion with consequent decarburizing of a zone of metal behind. In this zone, which is rather narrow it is true, the carbon may build up to 0.5 per cent as a conservative estimate. This appears clearly after a very short anneal and is illustrated in micrographs Nos. 9 and 10.

This phenomenon is attributed to the high temperature gradient

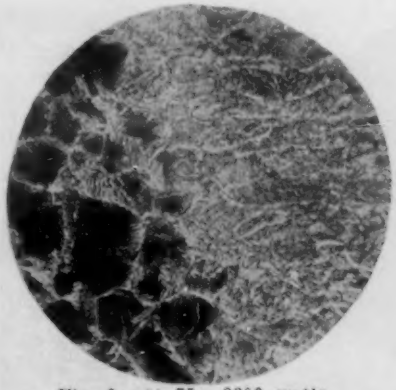


Fig. 9. × 75. 2200 watts

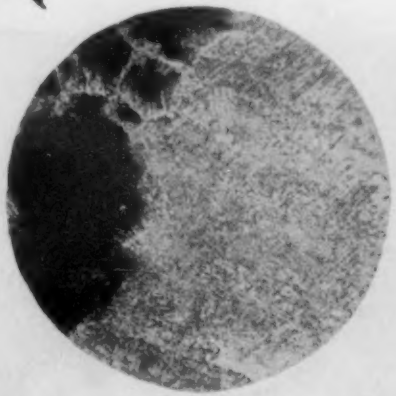


Fig. 11. × 75. As welded. 3600 watts

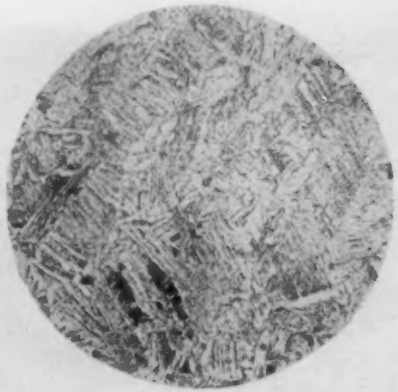


Fig. 13. × 75. 5500 watts

Fig. 10. × 75.

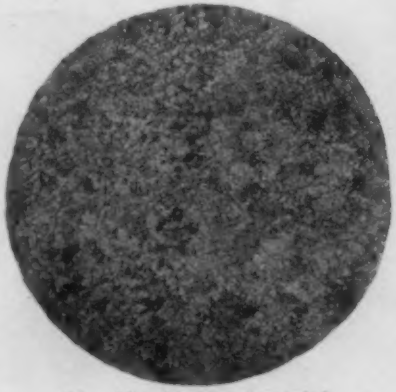


Fig. 12. × 75. Annealed

Fig. 14. × 75

which is set up when the arc is struck causing a carbon solubility differential, and a resulting movement of the carbon from a zone of lower temperature to one of higher temperature. When reversed polarity (plate negative) is used this condition is exaggerated, because the temperature gradient is steeper.

It has been found that by increasing the welding current this

Fig. 15. × 75. Unannealed cracking through zone of high carbon

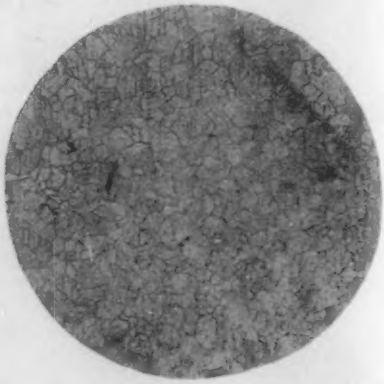


Fig. 16. × 75. Annealed high quality low carbon plate, showing zone of fusion. 250 amperes, 26 volts

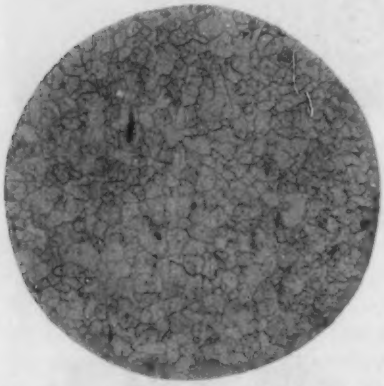


Fig. 17. × 75. Annealed high quality, low carbon plate, showing zone of fusion. 300 amperes, 26 volts

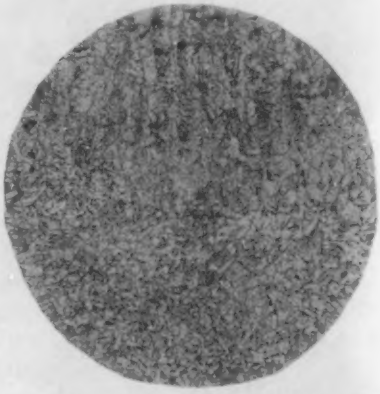


Fig. 18. × 75. Unannealed high quality, low carbon plate, showing zone of fusion. 350 amperes, 25 volts

migration gradually decreases, but that for reversed polarity the current must be higher than for straight polarity. Micrographs Nos. 9 to 14 show a series of weld junctions, both as welded and annealed, which have been made with increasing currents. They show not only the decrease in migration, but a big difference in structure of the deposited metals. The columnar grain is not so decided in case of the high current weld, and furthermore is broken up completely by annealing.

The effect of this migration of carbon is to produce a brittle zone through which fracture occurs on impact. Micrograph No. 15.

Micrographs Nos. 16, 17, 18, 19 show a group of structures obtained when low carbon, high quality steel is welded, with increasing currents.

Nos. 16 and 17 have been annealed showing that in the absence of carbon in the plate no migration zone occurs, and that the grain of the deposit is completely equiaxed. Nos. 18 and 19 show the "as welded" structures when 350 to 425 amps. are used. No. 19 compared very favorably with the annealed structures in that the grain of the deposited metal is nearly equiaxed.

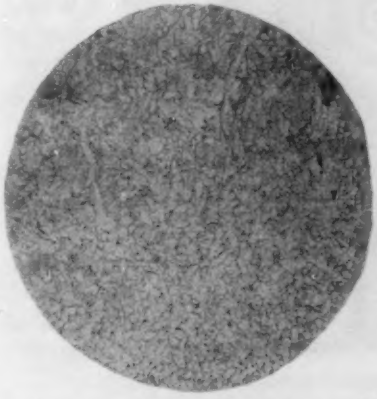


Fig. 19. × 75. Unannealed high quality, low carbon plate, showing zone of fusion. 425 amperes, 28 volts

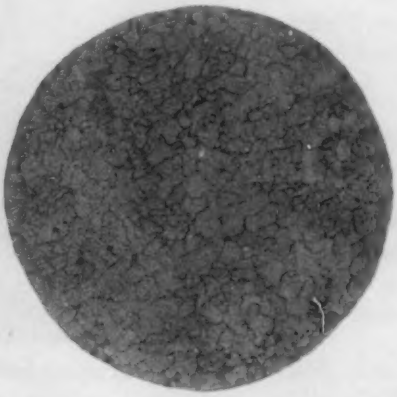


Fig. 20. × 75. Annealed. Hydrogen shielded deposit

This and the preceding series indicates that high current welding has considerable merit in that the dangerous zones are eliminated and that the grain of the deposited metal is more nearly equiaxed, and therefore considerably more ductile.

Hobart, in discussing Cox's paper on "Application of Welding to Ship Building" in November, 1918, showed both increasing strength and ductility for increasing welding currents.

However, the current density on the electrode must not be overlooked, so that in order to keep the correct values the electrode diameter should be increased. Work along this line is still in progress with a promise of yielding good returns.

Gas Shields

The hydrogen shielded arc process has been described on several occasions by Alexander who has accomplished a great deal with gaseous shields in general. Hydrogen, for purity of the deposit, is probably superior to all other gases. Fig. No. 20 is a micrograph of the annealed structure of a hydrogen shielded deposit and shows the freedom from the usual contamination. This weld has high ductility and in the "as welded" state has good strength.

The use of alcohol vapor as a shield has recently yielded some remarkably good results, and has the advantages of convenience and lower arc voltages. The deposits are very ductile and strong

and free from oxide inclusions. Nitrogen and carbon, however, are present in small quantities, but not sufficiently high to reduce ductility below a practical value and porosity is decidedly lower than in an unprotected arc deposit.

The method of using alcohol is to allow the liquid to drip on and run down the electrode. At about ½ in. from the arc the alcohol is vaporized and burns with a generous flame. Care must be taken

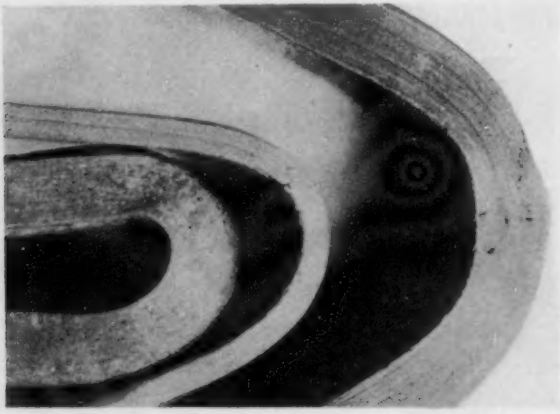


Fig. 21. Alcohol shielded welds

that none of the liquid alcohol drips directly on the molten metal, because if this happens there is an explosion which blows the molten metal out of the pool and leaves a large depression in the bead.

The most satisfactory results are obtained with bare or polished electrode wire, even though the arc is rather rough. The rust coating usually used on electrodes seems to react with the alcohol, giving a great deal of porosity and reduces the ductility of the weld.

The welds shown in Fig. 21 were made with 3/16-in. diameter mild steel wire, polished; 280 amperes, 26-28 volts, and the bead laid down at the rate of 6 in. per minute. The ¼-in. plates required one bead and the ½-in. plates two beads. The third weld shown is a bead laid on a plate. All of these show remarkable ductility and high resistance to bending.

In view of the fact that these welds contain both nitrogen (Fig. 8) and carbon, in appreciable quantities, and are still ductile, it can be concluded that oxide is the chief embrittling agent in ordinary open arc welding.

It is realized that the subjects discussed in this paper have not been treated in as great detail as is desirable, but that is because of the number and variety of subjects included. The conclusions arrived at in some cases are not in agreement with those of other investigators, and when the work now under way is completed, perhaps the present views will be modified. A number of new subjects for investigation have been presented since this work was started and will be reported at some future time.

Welding in the Design of Steel Plate Work*

LOUIS J. SFORZINI†

Plate work is, perhaps, the largest and, at the same time, the most diverse field to which welding may be and is being applied. Welding in plate work is not only encroaching on other methods for fabricating plate work but, in some instances, is even causing welded plate work to be substituted for such work as castings. Some of the common uses to which plates are applied are as tanks, pressure vessels and all types of containers; tubes and piping; hoppers, chutes and bins; air and other gas ducts; smoke flues, breechings and stacks; shipwork; cars and other vehicles; as part of structural members; as part of machinery members; as parts of conveyor systems; gear guards, etc.

There are six general processes by which plates may be fabricated into desired articles, these are cold drawing and working; hot working and forging; brazing; riveting; fire welding, and fusion welding. Of these only two, riveting and fusion welding, may be employed for nearly all the classes of work mentioned. Therefore, this paper will be confined mainly to a discussion of these two processes. But, before leaving the others, let us point out their advantages in certain classes of work.

Cold drawing and working is of importance in putting work into such shape that it may be completed by one or more of the other processes and for light plate work, i.e., plates of such thickness that they are practically sheets rather than plates. Brazing is of relatively small importance and is used chiefly as a seal for work formed by one of the other processes. Forging and hot working in plate work is used to a limited extent in preparing work to be completed by certain of the other processes. Hot drawing is of importance in forming seamless tubes and seamless tube specialties from plates. Fire welding is the process employed in the manufacture of commercial welded tubes and pipes from plates and covers a wide range of sizes, from as small as ⅛-in. diameter for butt welded pipe to 120 in. in diameter or more for hammer welded pipes. In addition fire welding has been developed to a point where it may be employed for forming a complete pressure vessel and its use is permitted for any purpose where riveting is used in vessels designed according to the pressure Vessel Code of the A. S. M. E., whereas, fusion welding has certain limitations imposed on it. Anyone interested in a comparison of the various processes used in the fabrication of pressure vessels is referred to a paper by the writer in the April 26, 1927, and May 3, 1927, issues of *Power*.

There is a large variety of joints that may be used for riveted

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and a large variety that may be used for welded work. The particular joint to be used for either riveting or welding is dependent on a multitude of factors and should be determined for each particular job. Fig. 1 depicts some of the common joints used for riveting and some of the joints used for welding. We will first study the riveted joints because, historically, they are much older.

The single riveted lap joint is the simplest riveted joint to make, but its efficiency or ratio of strength per unit width of joint to the strength of unit, width of original plate is relatively low, being about 58 per cent for a joint of proper design.

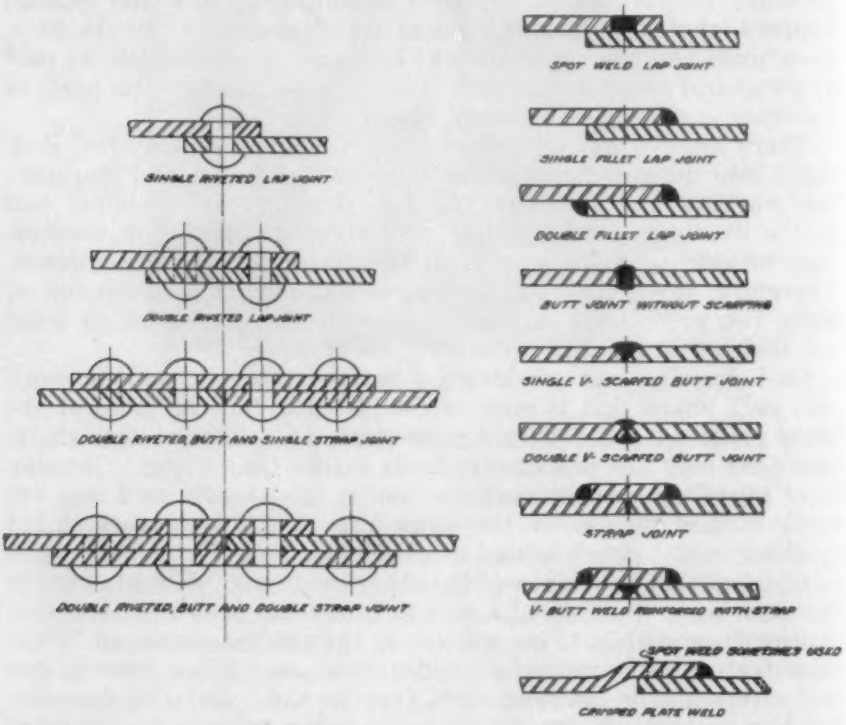

SINGLE RIVETED LAP JOINT
DOUBLE RIVETED LAP JOINT
DOUBLE RIVETED, BUTT AND SINGLE STRAP JOINT
DOUBLE RIVETED, BUTT AND DOUBLE STRAP JOINT
SPOT WELD LAP JOINT
SINGLE FILLET LAP JOINT
DOUBLE FILLET LAP JOINT
BUTT JOINT WITHOUT SCARFING
SINGLE V- SCARFED BUTT JOINT
DOUBLE V- SCARFED BUTT JOINT
STRAP JOINT
V- BUTT WELD REINFORCED WITH STRAP
SPOT WELD SOMETIMES USED
CRIMPED PLATE WELD

Fig. 1. Comparative designs of riveted and welded joints

By adding a row of staggered rivets we obtain the double riveted lap joint of about 69 per cent efficiency.

The double riveted butt and single strap joint is costlier than the double riveted lap joint, but has the same efficiency if the pitch and rivet size are the same, and if the thickness of the strap is at least equal to the thickness of the plate.

The double riveted butt and double strap joint is a still more elaborate joint. The rivets in this point have two different pitches, the pitch of the outer two rows being twice that of the inner two rows. A properly designed joint of this type has an efficiency of about 82 per cent.

There are two other still more elaborate classes of riveted joints, the triple riveted butt and double strap joint with an efficiency of from about 83 per cent to about 88 per cent, and the quadruple riveted butt and double strap joint with an efficiency range from about 87 per cent to 94 per cent. These are not illustrated.

Of the riveted joints shown, the single riveted lap joint is most commonly encountered in flat plate work. The double riveted lap

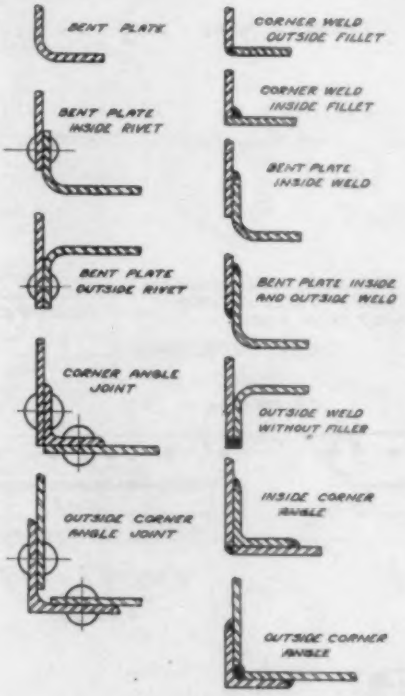


Fig. 2. Right angle riveted and welded joints

joint is used to a very limited extent on flat plate work, but is a common joint for longitudinal seams on moderate pressure tanks and as a circumferential seam on high pressure tanks. The double, triple and quadruple butt and double strap joints are used chiefly in tank and pressure vesssel work and are not often encountered in flat plate work.

The first welded joint shown, the spot weld joint, is somewhat similar to the single riveted lap joint and is used for comparatively thin plates only, but for the same pitch and diameter hole it cannot ordinarily be made as strong, because complete fusion is difficult in this type of joint. To be equal the ultimate shearing value of the spots must exceed 40,000 lb. per inch.

The single fillet lap joint can be made either with a continuous

fillet or with the fillet in stitches. This joint can be made as strong as the original plate when only the simple stresses of tension, shear and compression are considered, by a proper design, proper welding material and proper welding procedure. But, ordinarily,

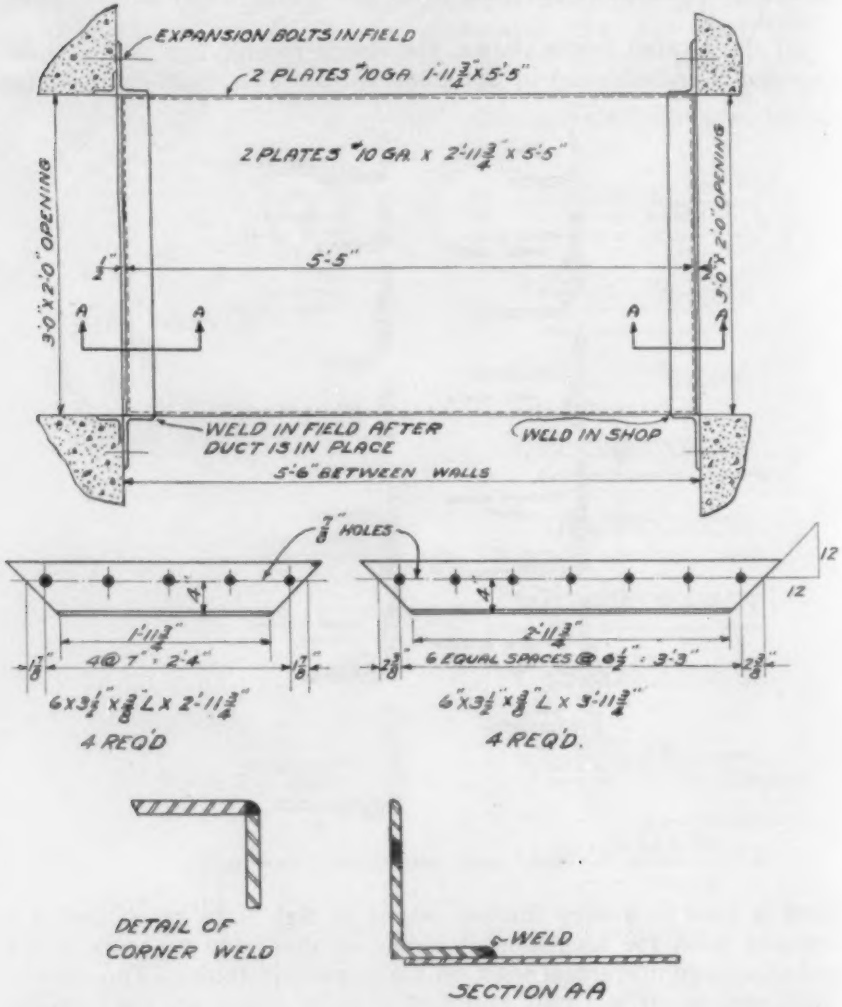


Fig. 3. Duct designed for welding

compound stresses are introduced by this type of joint, especially when used for tank work.

The double fillet lap joint is a superior joint to the single fillet joint and does not introduce as great compound stresses. Either or both of the fillets can be made continuous or in stitches, or a combination of continuous fillet on one edge and stitches on the

other edge may be used. The lap on this joint may be considered as a stiffener on flat plate work.

The butt joint without scarfing is used commonly for thin plates only, under ⅛-in. thick being usual. This joint is invariably made with a continuous weld.

The single V-scarfed joint is an excellent joint for plates up to about ¼-in. thickness. This joint is made continuous and can be designed and fabricated with a resultant strength greater than that of the original plate.

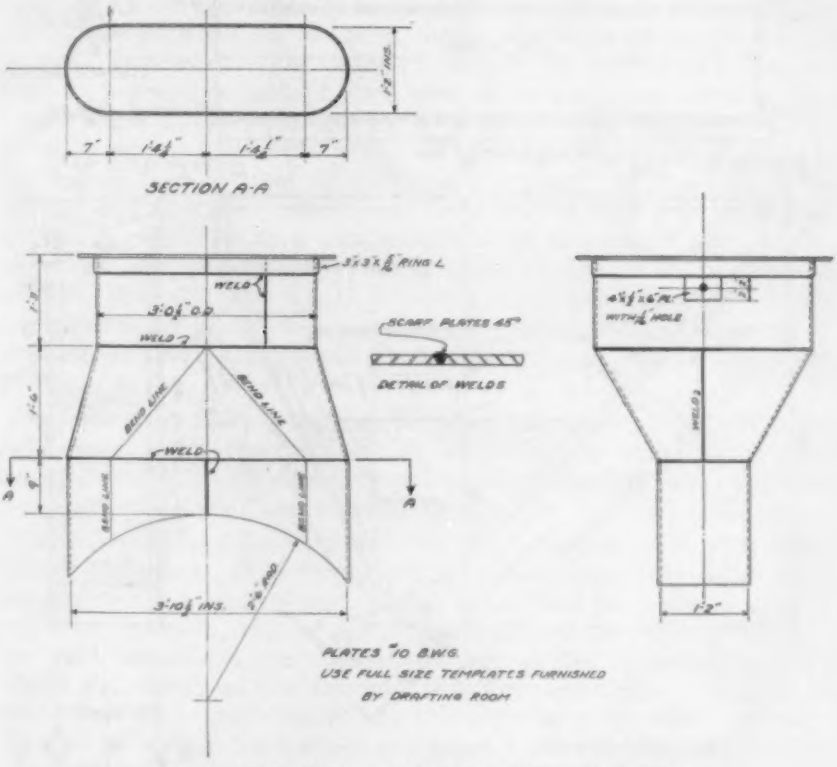


Fig. 4. Welded connection between boiler and stack

The double V-scarfed butt joint is another high class joint and should be used for plates over ¼ in. in thickness in tank work and where high tensile strength is required. This joint can be designed so that the tensile strength is greater than that of the original plate. It is superior to the single V in that better fusion and penetration can be obtaned from working both sides—it should not be more expensive than the single V to fabricate.

The strap joint is similar to the butt and double strap joints in riveted work, but is much simpler and should be less expensive. For simple stresses this joint can be made as strong as the original plate.

The crimped plate joint is a special joint not much in use.

The V-butt weld reinforced with strap is a combination of two of the other joints. The strap can be a continuous band or in plate strips only.

In computing the strength of riveted work properly done the factors involved are type of joint, size and spacing of rivets,

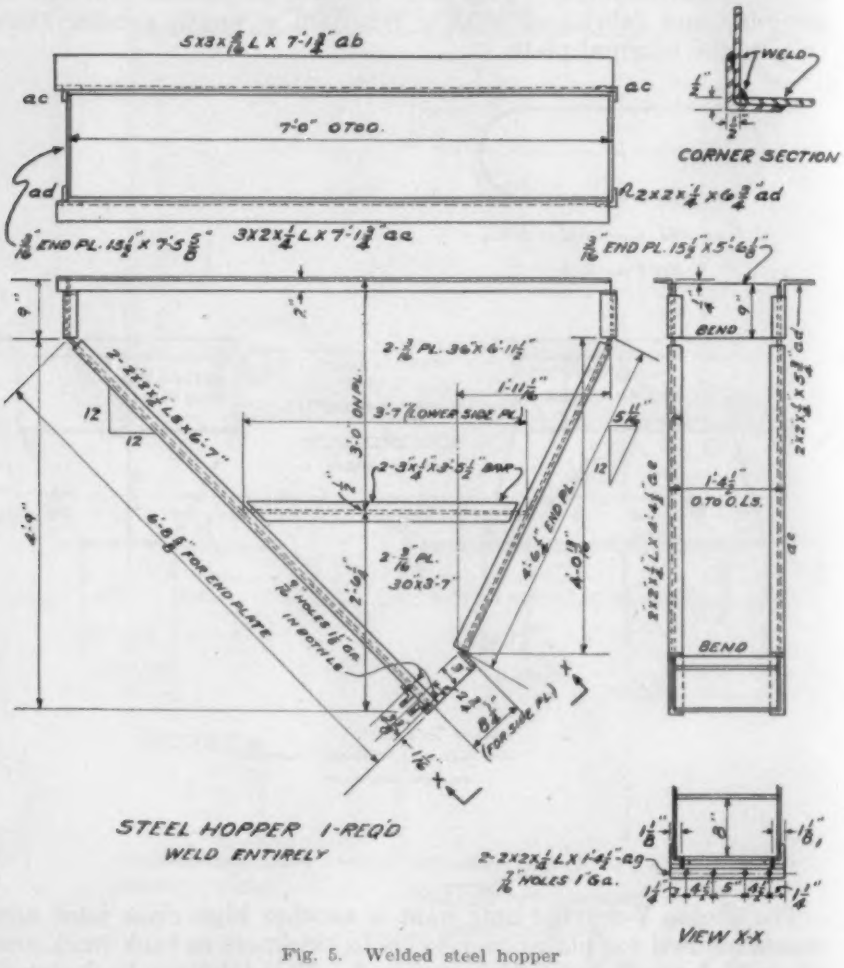


Fig. 5. Welded steel hopper

physical properties of the plate and physical properties of the rivets. In computing the strength of the welded work, also properly done, the factors involved are type of joint, dimensions of completed joint, physical properties of the plate and physical properties of the fusion material. A riveted joint can never be as strong as the original plate because material is cut out for rivets, although by making the joints more and more elaborate it can closely approach

the strength of the original plate. The ultimate strength of the plate material is taken as 40,000 lb. per square inch for tank steel, 45,000 for welding quality steel and 55,000 lb. per square inch for flange and firebox plates. The strength of iron rivets in single shear is taken as 38,000 lb. per square inch, and for steel rivets as 42,000 to 44,000 lb. per square inch. A factor of safety of 5 is usually used. The strength of deposited weld metal seems to be a matter for difference of opinion. The Pressure Vessel Code of the A. S. M. E. setting the limit at 5600 lb. per square inch, in tension, which corresponds to an ultimate strength af 28,000 lb. per square inch with a factor of safety of 5 with no specified type of rod. Others give the value from 6000 lb. per square inch to 8000 lb. per square inch of plate section for shear and tension with a high grade welding rod and the weld metal being built up 10 to 25 per cent above plate thickness. This means 30,000 to 40,000 lb. per square inch if a safety factor of 5 is used. If the high value of 8000 lb. per square inch is used for a welded joint, say, of double V-type, it would be on a competitive basis as regards plate thickness with a riveted joint in flange plate of 11,000 lb. per square inch working stress and 8/11 or about 73 per cent efficiency, which corresponds to a double riveted, double strap joint. The cost of making up the joint would then determine which is the most economical.

But for most plate work, i.e., for practically everything but pressure vessel work, the thickness is determined by other factors besides strength in tension. Some of these factors are stiffness, corrosion resistance and erosion resistance.

In fabricating riveted plate work it is necessary to first compute the spacing. Then to lay out the holes accurately either on a template or on a plate direct. Then to transfer the holes to at least one other member, taking particular care that the holes will register when assembled. The holes are now drilled or punched, after which the members are brought together, assembled and held in place with bolts and finally are riveted either by blows or pressure. For certain high grade work the holes are punched smaller than the finished size and reamed to size by reaming through the entire thickness of joint metal simultaneously. For the highest class of work punching is discarded entirely and drilling and reaming substituted. If the riveted work is to serve as a container, the further operation of caulking is necessary after riveting, caulking also requires another operation, that of beveling the plate for caulking before riveting up. It is thus seen that numerous operations are required to make up a riveted joint even of the simplest kind, and as the type becomes more complex the greater is the work entailed, and, of course, the greater becomes the cost.

Let us now consider the work involved in making up the welded joints previously described. We will omit the first and last joint in the illustration because they are not as common as the other

joints. Any of the lap joints can be made without any joint preparation (the plates, of course, being cut and formed to the proper size and shape the same as riveted work). All that is necessary is to bring the members to be joined together and to keep them in place with a few tack welds. The butt weld without scarfing also needs no preparation. The three scarfed joints require beveling on two or four edges. The beveling can easily be done by bevel shearing or on a plate planer usually available in plate shops, or

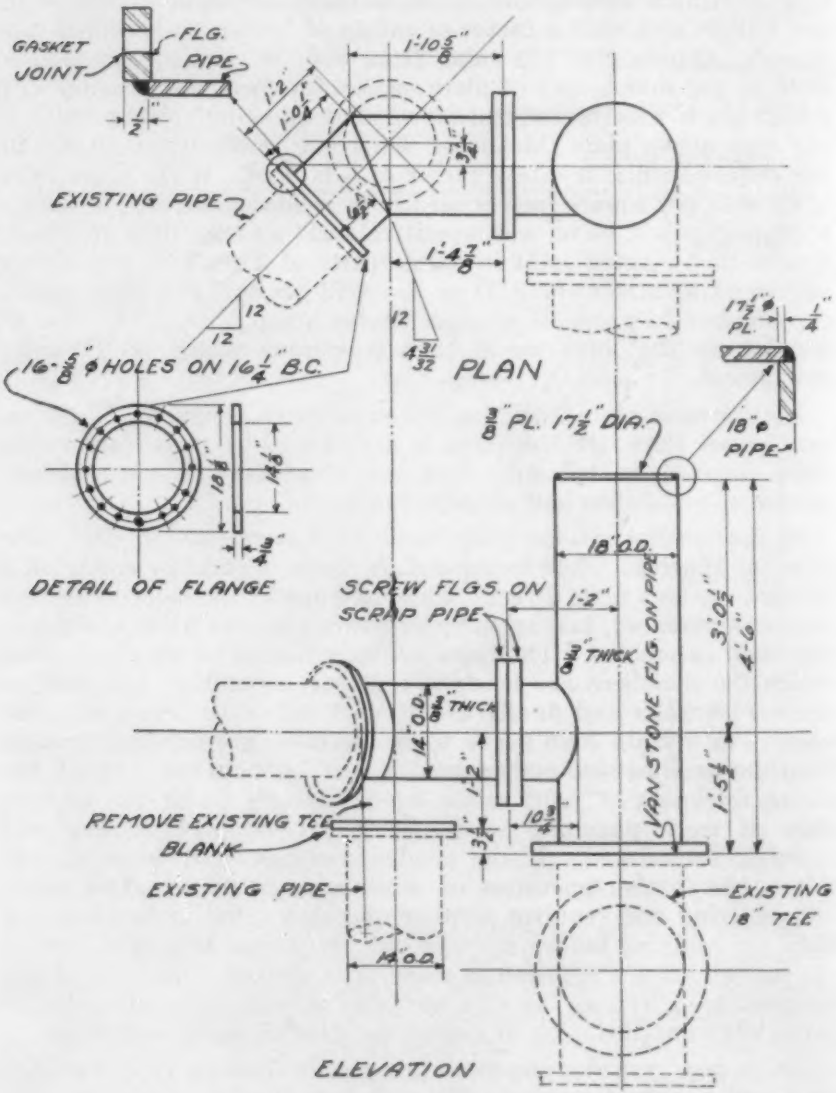


Fig. 6. Making new connection to pipe line

the beveling can be done by an air chisel or it can be done by burning of the edges.

To sum up the comparison, riveting requires a minimum of four operations, (1) determination of the rivet spacing; (2) laying out the holes on at least two members for every joint; (3) punching the holes, and (4) riveting. If the plate work is for a container, the two additional operations of bevel planing and caulking are required. Welding only requires one or sometimes two operations, whether for containers or not, the actual welding and sometimes scarfing, usually of two edges. This factor of simplicity of welding over riveting is one of the reasons why welding is being introduced more and more into the plate field.

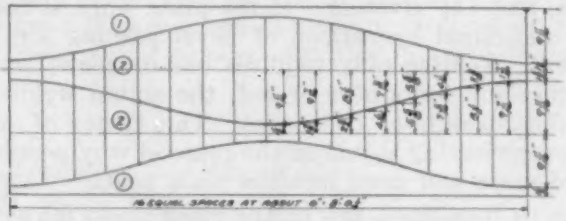
Let us consider a few of the right angle joints both for welding and riveting. In Fig. 2 the first illustration is of a bent plate and while shown in the column with riveted joints, it can also be used with welded work. This bend requires special equipment for bending if the plate is thick and large. If bending equipment is not available a corner angle must be used for riveted work. An equivalent welded corner joint, as shown to the right, can be made with an inside or outside weld, and can be continuous or in stitches, and is made up without special equipment. Two riveted joints with bent plates are shown, and to the right are three equivalent welded joints. The welded joint without filler can be made either oxyacetylene or with the carbon arc. At the bottom are shown two riveted jonts with corner angles and two equivalent welded joints, the weld of which can be continuous or in stitches. All the joints shown are equally applicable to flat or cylindrical plate work.

Fig. 3 illustrates a very common type of shop job, one that can be done in any shop possessing a plate shear and welding equipment, oxyacetylene or electric arc. This is one of two similar ducts, designed for 6 in. water pressure, and went between two existing concrete walls with gasket bearing. The material required was four pieces of plate and eight pieces of angle, and the illustration shown is the combined detail and erection drawing.

Note that the exact plate sizes and angle lengths are specified, so that all that is necessary in the shop is to shear the plate and angles to the sizes specified, to drill or punch the holes and to weld. The only laying out required is for the expansion bolt holes. No scarfing is required. The plates and angles are held in place for shop welding by simple fixtures, which any shop doing welded plate work will soon develop. Note that one of the flange angles is loose for field welding, because walls, as a rule, are extremely uneven and would require large clearance, and it would have been difficult to obtain a tight duct. The advantage of this duct over a similar riveted joint is that with the facilities available it was cheaper, and it was also cheaper than a purchase riveted job. Further, the job was absolutely tight and would un-

doubtedly remain so, which probably would not have been the case with riveted work.

Fig. 4 depicts a connection piece between an H. R. T. boiler and stack. This job can be made welded or riveted easily, it was made



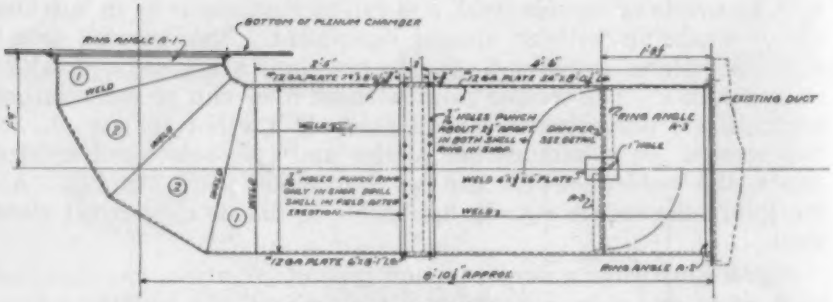


Fig. 7. Welded air duct

welded because it was simpler to do so with the facilities available. All the plate welds are single V-scarfed. In this particular case templates for the lower two pieces were made full size on paper. The ring angles and bearing plates were also welded.

Fig. 5 is more complicated than either of the other two jobs shown. The steel hopper is used for fine ashes, and was made up entirely welded. While it may seem to some that the heavy ¼-in. bottom and 3/16-in. sides and angles for the corners add unnecessarily to the expense, experience with ash hoppers indicates that if steel in this type of construction is to last any length of time against corrosive and erosive influences it has to be heavy. In riveted work of this nature, the corner rivets are usually the first to fail if the plates are thick; if the plates are comparatively thin the bottom plate fails first. Note the simplicity of the dimensioned detail for welded work. Everything is figured for the shop; the angle lengths are all specified; the plate overall sizes are specified,

and complete dimensions are given. All that is necessary for the layout man to is to lay out the plates to the dimensions and bevels given.

Fig. 6 is an excellent example of why welding is being looked upon by the designer as a good ally. Two existing 14-in. water pipes were connected by an elbow. It was designed to break the connection and to make a new connection to an adjacent existing

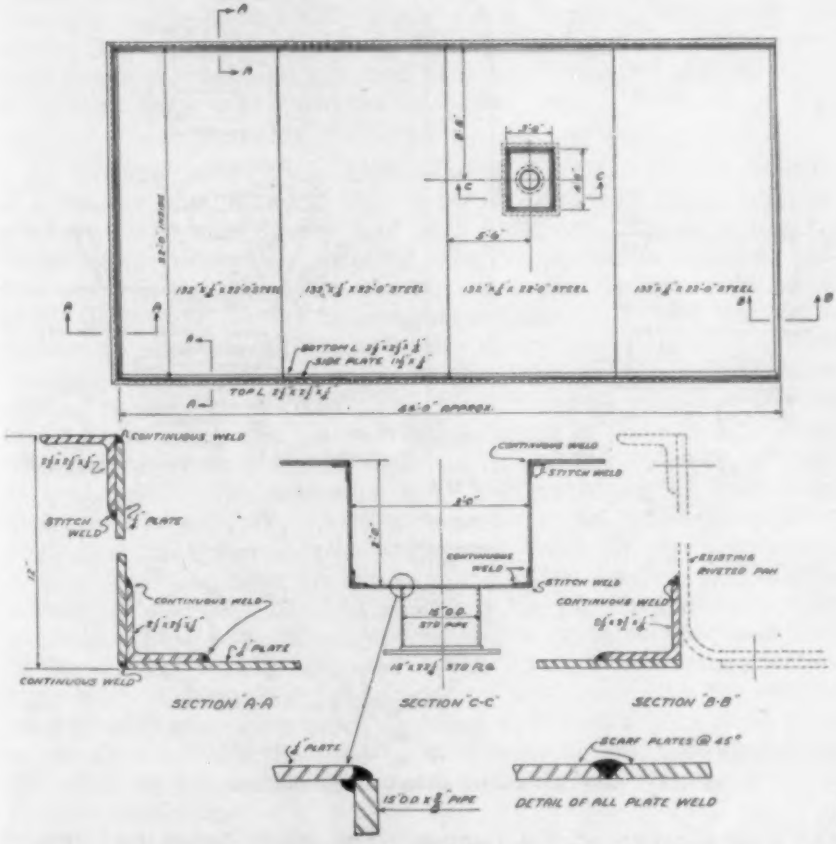


Fig. 8. Welded roof tank

18-in. line. Before the days of welding it would have been necessary to procure a 14 in. ell, an 18 in. x 18 in. x 14 in. tee, 4-14 in. flanges, 2-18 in. flanges, cut and thread three new pieces of pipe and screw up the flanges. The piece of pipe under the 18 in. tee, not shown, went through a floor, and would have to be shortened, which means it must be dismantled, the floor torn up, the piece brought to the shop and taken back again. In addition eight new sets of bolts and gaskets would be required.

Now contrast with this the illustration which shows the way the job was actually installed. The 18 in. x 4 ft.-6 in. piece was made from a piece of scrap pipe with Vanstone flanges already on. The 17½ in. disc was cut from a ⅜ in. plate with the cutting torch and welded with a fillet weld. The two pieces welded together at an angle, and the adjacent piece welded onto the 18 in. pipe, were all made from scrap pipe utilizing flanges already on

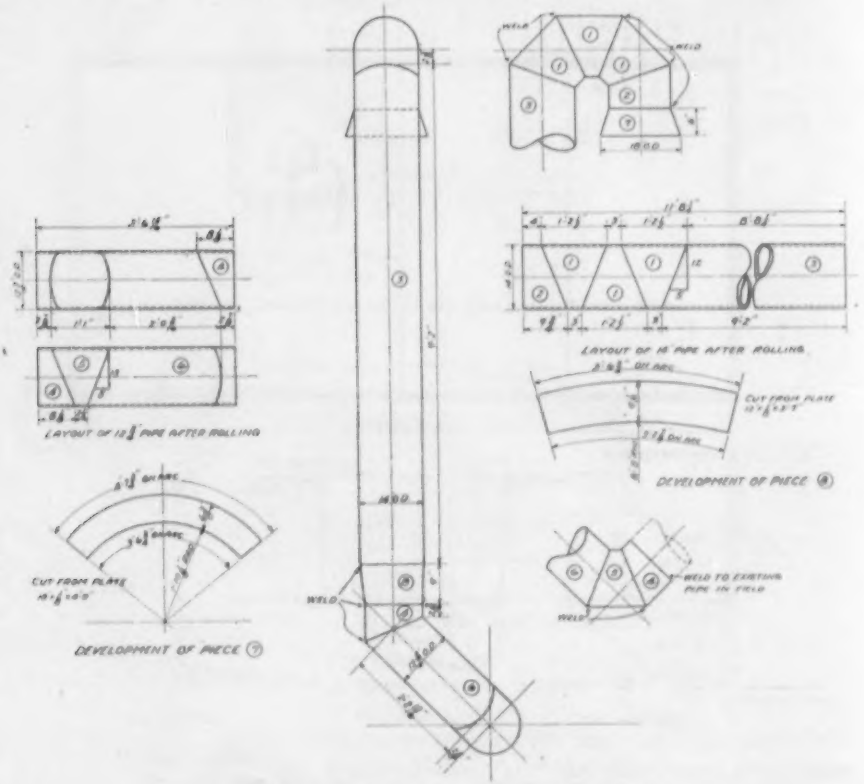

LAYOUT OF 12¾ PIPE AFTER ROLLING
LAYOUT OF 18" PIPE AFTER ROLLING
DEVELOPMENT OF PIECE ⑨
DEVELOPMENT OF PIECE ⑦
WELD TO EXISTING PIPE IN FIELD
WELD

Fig. 9. Welded compressor suction line

the pipe for two of the flanges. The other flange had special drilling and was made from a rolled bar welded to the pipe. Only three new gaskets and two sets of bolts are required. The 2-14 in. screwed flanges could have been omitted were it not for ease of erection. The writer would estimate the cost of the welded scheme to be about one-third that of the alternate scheme. If scrap pipe was not available it could and would have been made from rolled ¼ in. plate with a longitudinal weld to form the pipe and with either ring angles or rolled bars to form the flanges.

Fig. 7 illustrates an example of work of circular cross-section. This is used as an air duct. The straight sections with longitudinal

butt welds are, of course, simple, as are the ring angles. The pieces for the elbow were all laid out in the drafting room by simple computation, so that all that is necessary to do in the shop is to lay out the coordinates to the dimensions given. Note that there is no waste of material. If the cutting is done by a torch, sufficient cutting allowance must be made. After cutting, the plates are rolled to a circular form and the longitudinal seams butt welded, the pieces are then tacked together and the circumferential welds completed. Four ducts were made welded as shown, four similar ducts were previously made riveted with a very good grade of workmanship, and both were installed side by side. A look at both will convince even the casual observer of the superior job obtained by welding.

An unusual field job is illustrated in Fig. 8. It was desired to construct a tank 22 ft. wide by 44 ft. long and 12 in. high to act as a water pan on the roof of a building. The tank was to be attached to another existing pan, as shown in Section BB. The shop doing the work was not equipped for shearing large plates accurately, or for bending large plates. It was, therefore, decided to purchase all plates to size direct from the mill instead of using commercial size from stock. The limits specified were plus or minus ¼ in. from size. Corner angles were substituted instead of bending the plates which is usual in plate shops. Note that there are four plates 22 ft. by 44 ft. and 110 linear ft. of plate 11½ in. wide. The only shop work performed on the four large plates was to scarf the plates with an air chisel. The top stiffner angle and the bottom corner angle were welded to the side plates to give convenient lengths for handling. The sump was also shop welded. Note the method of attaching the pipe to the sump with welding. This pan sat on a framework of metal I-beams high in the air and was to be bolted to the I-s with bolts made watertight with lead washers. The welding was done with the outside temperature averaging below freezing and with a high wind most of the time. While the welders were more or less protected from the wind by tarpaulins, the work, nevertheless, was done under adverse conditions.

At first it was attempted to weld the plates while they were free on the I-beams without bolting down. The skip system of welding was used and everything went along beautifully until the complete 22 ft. of butt weld between two plates was completed, when it was discovered that the weld was cracked at the center of the V- at about three places running from 8 in. to 18 in. in length. The second two plates proved ever more troublesome, the V breaking at the center of the pan after about 65 per cent of the plate length was welded up. It was then decided to bolt the plate down to the steel with three lines of bolts parallel to the length of the plate and at spacings of about 4 ft. and with four bolts at each spacing. As a further precaution eight or ten steel strips about 1¼ in. wide,

3 in. long and 5/16 in. thick were welded on the underside at the butt joint of each plate, drilling through one plate and strap for a bolt were any warping had occurred. The defective welds were then chipped out with air chisel and welded successfully. The plates were first welded together to give two plates 22 ft. by 22 ft. and these in turn were welded together to give the complete bottom.

The sides were now tack welded on. It was found that the edges of the bottom plate had sagged considerably, these were all pulled back up to the sides by a combination of C-clamping and drilling through and bolting the bottom plate to the side angle at places.

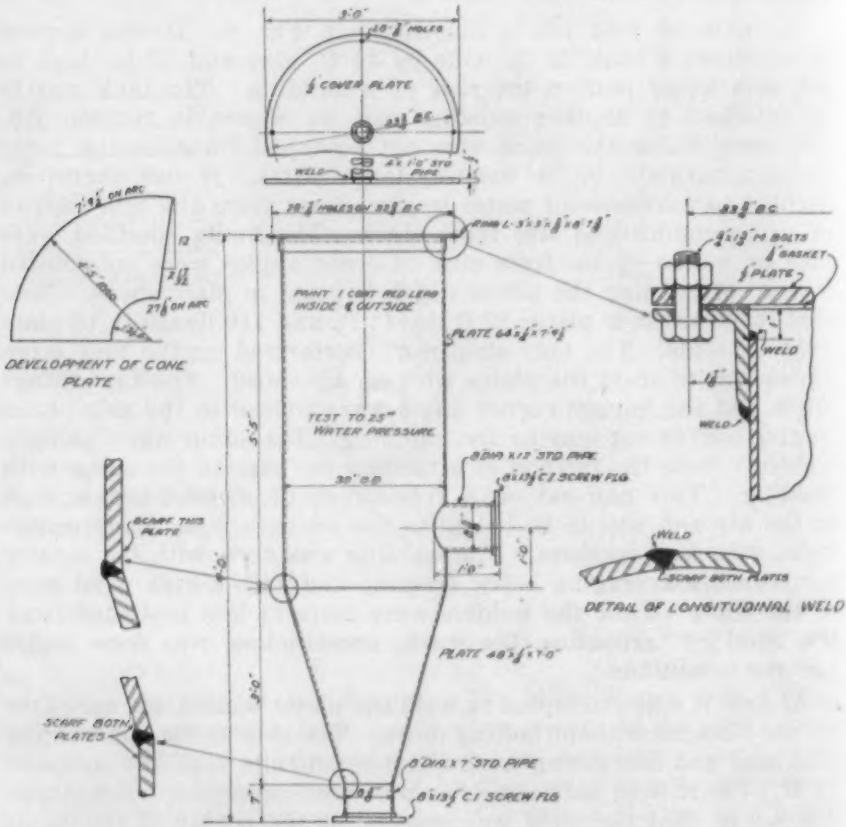

DEVELOPMENT OF CONE PLATE
PAINT 1 COAT RED LEAD INSIDE & OUTSIDE
TEST TO 25# WATER PRESSURE
SCARF THIS PLATE
SCARF BOTH PLATES
DETAIL OF LONGITUDINAL WELD
SCARF BOTH PLATES

Fig. 10. Plate flash tank designed for welding

When the sides were all welded on it was found that pulling the sides had caused a few minor cracks in the bottom plates and a few cracks where the bottom angles were welded to the bottom plate, these cracks were chipped out and rewelded successfully. The new pan was attached to the existing pan by welding an angle

as shown, and this was done without emptying the pan of water and without interrupting operation. A hole 3 ft. by 4 ft. was now cut through with a cutting torch and a sump was welded as shown.

This job ran into considerably more trouble than anticipated. Part of the trouble was undoubtedly caused by the unfavorable weather conditons, the balance was due to not being able to adopt the ordinary shop methods and fixtures to this job. In spite of this the cost was under that of a substitute riveted job.

Another pan, practically a duplicate, as far as dimensions are concerned, was later welded under summer weather conditions. Profiting by experience with the first pan, it was decided to substitute lap welds in place of butt welds for the bottom plates, using a continuous fillet on the inside of the pan, and stitches on the outside, the plates lapping 2 in. The bottom plates were bolted to the steel I's in the same manner as the first pan, then the lapped plates were bolted together with ½ in. bolts spaced every two to three feet. In addition, the plates were tack welded together, and to all the steel I-beams on which the pan set. Before any continuous welding was attempted the sides were tack welded to the bottom plates. In other words, the pan was assembled complete with tack welds before making the final welds. The extra preliminary work was more than justified, for when the continuous welds were made, no warping and not one crack occurred. The pan was fabricated at much less cost than the first pan.

In Fig. 9 we have a compressor suction line made from ⅛ in. thick plate. The plate layout is shown after rolling. The actual development is on flat plates and gives sine curves, the same as previously shown for 30 in. elbow. The taper development is shown. The 9 ft., 2 in. piece was actually made in smaller pieces with circumferential welds to accommodate the rolls available.

Fig. 10 illustrates a plate flash tank designed for 25 lb. per square in. working pressure. For certain installation and operating reasons it was advantageous to have the tank of the shape shown. Everything except the two C. I. flanges shown was welded. Starting at the top the 36 in. flange was made by cutting a half inch plate into a circular disc with the cutting torch, at the same time cutting out a hole for the 4 in. pipe nipple. The bolt holes were then laid out on this and punched. To complete the flange the 4 in. pipe nipple was welded in. The ring angle was rolled from a steel angle shape, the ends butt welded together, and then drilled, using the plate disc flange as a template. The 30 in. diameter cylindrical body was rolled from a rectangular plate and the ends butt welded as shown in detail. The 8-in. flanged pipe and the ring angle were welded to this body as shown in detail. The taper piece was laid out to the dimensions shown, rolled and the longitudinal seams welded, after which it was welded to the cylindrical body. Welding the bottom flanged nipple completed the job. As

made the tank cost less than half the cost of a substitute riveted vessel with no welding.

Fig. 11 depicts another field job. The plan shows that this is made up of a 11 ft. x about 54 ft. main part and two 14 ft. x 15 ft. branches. This is a plebum chamber in a stoker installation. Head room was at a premium, and for this reason it was made up of a combination of concrete and a shallow steel box. This required that part of the welding be done in close quarters with a head room of only 24 in. As shown in section B-B and detail, bolts were provided at a spacing of 12 in. in the concrete beam to take a 5 in. x 3½in. angle to support one side of the bottom plate. A steel side, built in the shop with welded top and bottom angles in convenient length panels, was hung from bolts on inserts, also at a spacing of 12 in., to take the other side of the bottom plate. Both angles bolting against the concrete were backed up with sheet packing to make the joint air-tight. The 72 in. plates were set on the two bottom angles. The cross stiffener angles were then suspended with rods from inserts also placed in the upper slab, and the plates were tacked to the stiffeners. Everything was then welded which, of course, involved both overhead welding and welding from a laying position. Considerable warping of plates and tares in welds took place but with the use of a few bolts the plates were pulled back into place and the welds completed. Manholes were made by cutting holes with the cutting torch, and then drilling a series of holes around these openings into which bolts were inserted and welded to take the manhole covers.

There were a considerable number of concrete projections, some of which are shown in the photo, but not clearly, around which the duct had to be built and made airtight. This was all taken care of in the field with the use of angles, plates and a few expansion bolts. The completed job was substantially airtight, and much cheaper than a substitute riveted job. The chief difficulty encountered was not in the actual welding but in rectifying errors or, rather, inaccuracies in the bolt and insert spacing in the concrete. These were set to specified dimensions, and the angles were punched to the same dimensions, and were in fact even slotted, but in spite of this fully 90 per cent of the angle holes did not register and considerable field fitting had to be done. To avoid this difficulty all similar jobs are now being done by providing a steel bar spacer, laid out simultaneously with the angles, to act as a bolt spacer in the concrete form.

The illustration shows how simple the drafting work, even for a large job, becomes when welded. The views shown in the illustration, with a few other minor details, were all the drawings used in making up the job.

All the examples shown were what is known as job work, i.e., one or at most a few of one item or similar items are made. In

riveted work which has reached a high stage of development, certain methods of manufacturing procedure, certain equipment and standard details which apply to all riveted work in general, have been evolved and are known and available to all doing riveted work. In the design and testing of riveted work, allowable stresses, factors of safety, material specification and so on, are also the result of years of experience.

On the other hand, fusion welding is a comparatively new art and is right at the start of its stage of development. Those manu-

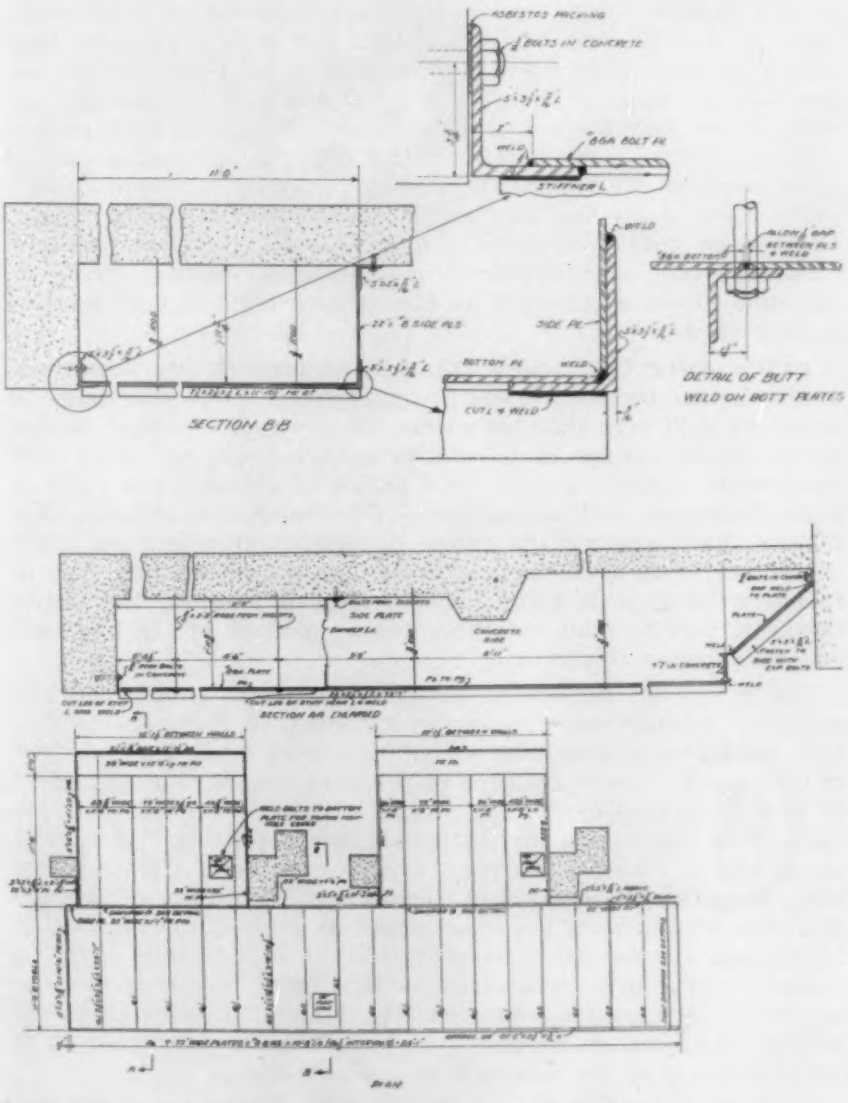


Fig. 11. Welded chamber in a stoker installation

facturing certain standard products on a quantity basis, where welding may be used to advantage, can experiment by the process of cut and try, until satisfactory equipment and procedure applying to the particular product are evolved. But with job work the fabricator must proceed immediately to make the finished product. One starting out to weld plate work is practically a poineer, and the start may be discouraging, but as he gains experience he also evolves certain methods of procedure, certain tools and certain fixtures which can be used for any plate work of a general nature. With each increment in experience the work is done more and more satisfactorily and economically, until eventually no shop job presents difficulties. But in field work considerably more pioneering remains to be done in the plate field, for the facilities available in the shop are not available in the field, and some of the field work is really difficult. With riveted work field erection is not difficult because field riveting is laid out so that all joint members are punched so that they may be held in place with bolts before doing the final riveting. However, the writer is of the opinion that eventually with increased experience, and particularly with free interchange of experience, welding will be on the same plane as riveting as far as simplicity of field erection is concerned.

In discussing the various examples no mention has been made as to whether the electric arc or oxyacetylene torch was used. It might be said here that both were used, whichever could be employed to advantage in a shop completely equipped with both equipment. Some examples were purely of oxyacetylene welding, some of electric welding, and some of a combination of both. The factors that governed the choice of equipment might not apply elsewhere, so in order not to make it appear that one type of fusion welding is better for one job than another, the writer thinks it best to omit reference to the method of welding in a general paper of this kind.

The thing that strikes the writer as being the chief advantage of fusion welding over riveting in general plate work—mind you, he is not advocating welding for all plate work at the present time, in fact, there is a certain type of pressure vessels that he prefers to have fabricated by other processes—is that practically any job can be fabricated with very little equipment. Cutting and welding equipment, a set of plate rolls, a drill press and a plate shear, being about all the equipment necessary to fabricate an average job. For certain work the shear might be omitted and the cutting torch used, and for flat work exclusively, the plate rolls might be omitted. Of course, work can be fabricated much more satisfactorily with increased equipment, the minimum was merely given. All the examples of welded work shown were fabricated in a maintenance shop not equipped as a plate shop.

In all the examples shown each particular job was designed and

drawn up for welding, and hence, satisfactory work and low cost were obtained. The writer is, however, familiar with certain jobs where the design and details were made up for riveted work, and when it was decided to weld the jobs, the only change made on the drawings was to place a note thereon: "Make of welded construction." Of course, these jobs were not entirely satisfactory from either a quality or price standpoint. While the average welder is a good mechanic and usually an ingenious individual, it is too much to ask him to take a job and material laid out for riveting and make the necessary changes to do the job with welding. Leaving questions of design to the welding shop is also one of the chief causes for failure in welded work. The designer of plate work should pay as much attention to welded details as he formerly did to riveted details. While welding is a new art, the principles involved are fairly simple, and with diligent study, do not require a long time to master them. Proper cooperation between the designer and the welding shop, will allow the welding art to hold the ground it has gained so rapidly in the last few years, and will also make for further progress.

Heat Treatment with the Oxy-Acetylene Flame*

E. E. THUM†

A proposal to use the oxy-acetylene flame for heat-treatment, supposing that such a proposal were made 40 years ago, would have been hailed with derision. Many superstitious beliefs were held in those days about the subtle influence of a certain kind of fire used to produce the heat or complex brew in which the metal was cooled. One of the greatest accomplishments of the modern science of metals is the penetration of these fallacies, and the substitution of a body of precise information about chemical composition of alloys and their correct heating temperatures and cooling rates to give desired combinations of strength, toughness and hardness. Therefore, today the underlying principles are well known, whereby the proposal can be judged on its merits.

It may be stated at once that the proper application of the oxy-acetylene flame to heat treatment is somewhat limited. Nevertheless it is important, even when confined to local hardening or an-

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†Associate Editor, *Iron Age*.

nealing (or in other words, heat treatment of certain spots on a larger unit).

The whole trend of modern heat-treatment has been toward uniformity and neutral gas atmospheres within the furnace; toward an accurate control of the temperature by pyrometers; toward standardized routine which insures that each one of thousands will receive exactly the same treatment. Consequently it might appear unorthodox and a step backward to propose the small oxy-acetylene flame for heat-treatment applied by hand, and without pyrometers to measure the effect. Such a supposition does not consider the fact that the oxy-acetylene flame is most precisely and completely controlled, its temperature, though high, is unvarying; the gas atmosphere is neutral, without chemical effect on

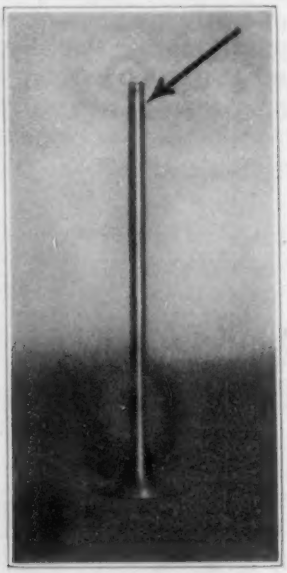

Fig. 1. Motor valve-stem: hardened at end

the heated metal; and finally, the action in production is so rapid that the operations proceed with a rhythm and smoothness which is the ideal of production engineering.

The most widespread use of oxy-acetylene flame for heat-treating is for emergency hardening of small metal cutting tools, like lathe tools, milling cutters and drills. Suppose it is necessary to prepare two or three tools in a hurry. Instantly the oxy-acetylene flame is at full heat; the cutting edge of the tool may then be brought to temperature gradually by brushing the flame back and forth. (Gradual heating, of course, is necessary to prevent risk of cracking the tool.) At the correct time it is plunged into water. The job is done before the forge fire could be lighted!

On the face of it, such practice is unscientific. It reverts to the "human-eye pyrometer," and the human eye is quite uncertain when judging high temperatures by color. But it should be remembered that enormous numbers of tools are hardened daily with a good degree of success in a blacksmith's forge, and the temperature judged by eye. Hardening with the oxy-acetylene flame merely follows this practice, and the added advantage of a clean, uniform, high heat produced by a neutral atmosphere.

The oxy-acetylene flame also possesses the large reserve of heat necessary for the excessively high temperature required when treating high-speed steel, a temperature unattainable except in very well designed furnaces. High-speed steel should be quenched from a "sweating temperature"—at that heat the edge and corners glaze and seem to be at the very verge of melting. This appearance is entirely independent of color, and can be easily observed through ordinary welding goggles.

Emergency work may be done with economy and dispatch with the oxy-acetylene flame. Suppose a hardened screw-cutting tap

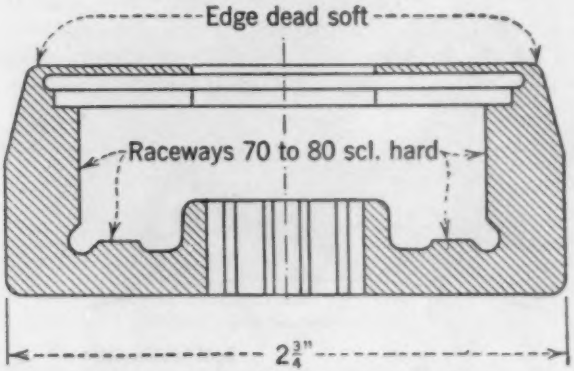

Fig. 2. Ball race; softened at upper edge

freezes and breaks short off in the hole. It is easy to draw the temper by heating it to a red-heat, when it can be drilled out. Such annealing requires a heating to a temperature above a full red, and then a slow cooling. In general this means using a fairly large blowpipe flame, and withdrawing the flame from the heated spot with extreme slowness (especially if it is a small spot in a big mass of metal) in order that the cold surrounding metal may not draw the heat away so rapidly as to be in effect a self-quenching action.

Spot annealing is frequently done on steel sheet which has been heavily cold worked, say into a cup, yet must be further flanged at one region out into a spout or nozzle. Two men working on universal joint casings have a production of 500 per hour, heating a spot for punching and flanging for an oil drain.

Other metals besides steel harden on cold work to such an extent

that further bending or forming will tear or crack the article. Aluminum sheet is of this nature. The oxy-acetylene flame softens spots on cups, so dog-eared lugs can be further made, or spouts turned out. The correct annealing temperature of aluminum is a very low heat—just hot enough so that when a taper of paper is drawn across the spot it leaves a black mark on the metal.

While annealing in production is usually done on thin metal by a moderate sized flame, it is very useful in softening hard spots on castings. These are caused by hard running or an unexpected chill, and give a lot of trouble to the machine shop which does not know how easily they may be softened with the blowpipe flame. Owing to the more brittle nature of castings, such hard spots must be heated very gradually, and a considerable amount of the surrounding metal heated at the same time. Furthermore, the temperature should not extend beyond a very low red, unless the hot spot is at an edge or corner.

The most important annealing application is found in what is called localized case-hardening. Very often it is desirable to case-harden only part of the surface. For instance, camproller pins must be very hard in the body to resist wear and the ends soft enough to be riveted into a tappet. Partial case-hardening is not very easy. In the past it has been the practice to cover the places to be soft by an impervious substance or by copper plating, then

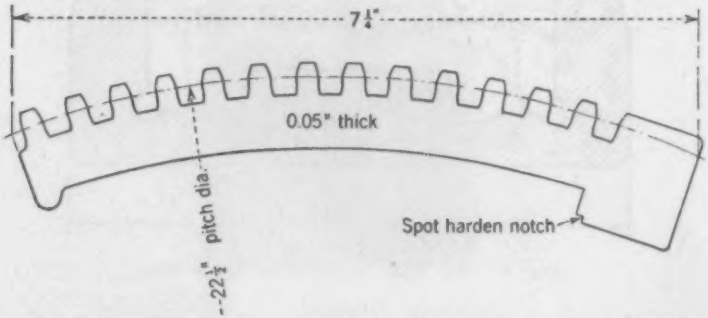

Fig. 3. Rack for adding machine; hardened at lower right corner

pack the parts in carbonaceous materials and heat in the usual way. Often, however, the protection was not complete; the regions desired soft have an exasperating way of coming out hard! After softening these spots, almost without number, by the oxy-acetylene flame, the metallurgist had an inspiration. "Why bother with the coating? I'll just harden them all over and soften the parts I want soft with the flame." Such a scheme is now frequently used in production, with excellent results.

Hardening of a wide variety of pieces is done with the oxy-acetylene flame—usually on parts which require hardening of only a portion of the surface. Take as an instance the little segmental gears used in adding machines. They are punched from 0.50 per

cent carbon steel sheet, 0.05 in. thick. Only the stop at one end needs hardening. It takes about 2 seconds to bring this corner to heat and drop the piece into water.

Similar hardening in large scale production is done on valve stems for gas engines. These consist of a thin round rod rising from the center of a small circular plate. Only the tip end of the rod needs be hardened. Such stems are made of alloy steels (usually having air-hardened properties) or various analyses, depending upon the ideas of the auto manufacturer, but they are

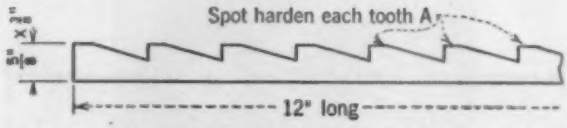

Fig. 4. Key-way broach; hard teeth, tough back

Fig. 5. Universal joint casing; annealed at oil drain

heat-treated in the same manner. A hundred or more are arranged regularly in a shallow pan, each one standing on the plate. This pan is then immersed in a circulating bath of water so that only about half an inch at the top of the rod appears. An operator then heats each stem in succession to the correct hardening temperature; the water bath cools the hot rod rapidly enough for correct hardness at the end.

About six minutes is needed for a batch of 100—that means about 3½ seconds each. The workman soon becomes accustomed to the cadence or rhythm of the operation, so he judges the heat as much by the length of time the flame is in contact, as by the color of the heated rod. This is good practice, because of the unvarying temperature of the oxy-acetylene flame.

As a third instance, take a key-way broach. It is cut from a high-speed rod, ⅜ in. wide by 12 in. long. It is very difficult to avoid a slight warping during hardening; if they are only hard

enough so they can be straightened after heat-treatment. This hardness did not give satisfactory cutting qualities.

To remedy this troublesome situation, the broach was firmly clamped in a tight fitting slot in a heavy cast iron plate, and the cutting edges were heated with the oxy-acetylene flame, one by one, gradually and uniformly to the sweating temperature, and the hot tooth immediately quenched with an air blast. This gave the maximum degree of cutting hardness to the edges, yet left the back soft and tough, easily capable of being straightened of any slight warping which might occur despite the restraint of the cast block.

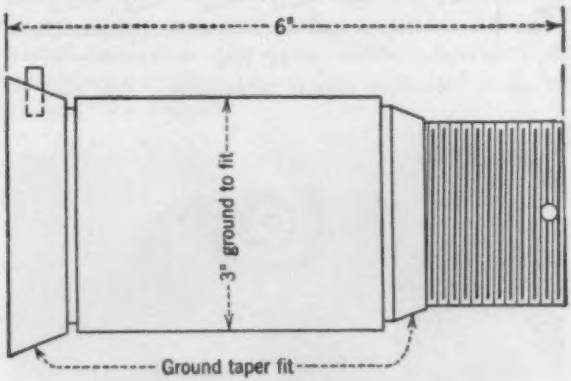

Fig. 6. Crank pin; annealed for cotter hole

Spot hardening of malleable iron is one of the most recent metallurgical developments. Very complex parts, such as rifle receivers, have been made in this way.

This piece must be machined to close limits all over, it must be tough to resist the shock of exploding powder, it must be hard in at least six regions, to resist wear of moving contacts; and finally it must not warp out of line in the least during heat-treatment. All these conditions are most easily met by spot hardening of high grade malleable castings. A malleable casting is the ideal material to machine; it is less expensive than either a forging or machine steel; in body it is tough and strong; finally, under the oxy-acetylene flame it may be spot hardened easily, raising its scleroscope number from the original 15 to an ultimate 50.

Malleable iron is seldom regarded as a metal susceptible of hardening. It resembles wrought iron in its softness and toughness. Furthermore, it is esentially different from steel, since it is an alloy of iron and free carbon rather than an alloy of iron and the compound iron carbide. However, it is found that under the quick sharp heat of the oxy-acetylene flame, the particles of free carbon dissolve readily in the iron crystals, and a satisfactory hardening results from a quick quench. However it is necessary that the

heating be intense and very brief. Herein lies the advantage of the oxy-acetylene flame.

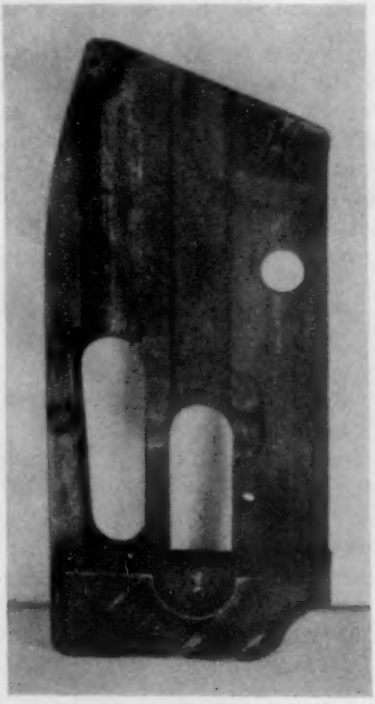

Fig. 7. Rifle receiver of malleable iron, spot hardened

By virtue of low-cost production, tough body, and satisfactory spot-hardening qualities, malleable castings heat-treated with the oxy-acetylene flame evidently hold out great economies in machine production.

Welding the Aircraft Structure*

J. B. JOHNSON†

An engineer who begins to lay out a structural design is confronted immediately by the problem of fastening together several miscellaneous members to form a useful assembly. Serious thought must be given to the method of joining. The fact that almost every aeronautical engineer in the country had adopted welding for steel airplane structures is good evidence of the superiority of this method. The further fact that welded structures have been used for over five years on every type of military airplane and there has not been a failure in service of a properly designed and properly manufactured welded joint is convincing evidence. Failures due to improper design have been corrected in practically every case by redesigning the joint but still using welding as the method of fastening. Failures due to unskillful welding have been comparatively rare and to the writer's knowledge have never caused a fatal accident.

An airplane structure consists of four main units—the wings, body or fuselage, landing chassis, and empennage or tail surfaces. The attachments between the various units and between the individual parts of each one are completed by means of sheet metal fittings.

The art of welding was naturally first used in the construction of these fittings, but only to a limited extent. The early airplane constructors distrusted it and preferred, if possible, to make a fitting out of a continuous piece of sheet steel, very often making complicated twists and bends in order to obtain the desired result. The distrust of welding was probably due to the fact that the aircraft was often built in a small factory and a skillful welder is not available; therefore, the workmanship was never entirely satisfactory.

The age of welding in its application of aircraft began when the oxy-acetylene torch was applied to the fabrication of the fuselage, chassis, and control surfaces. The development of the welded fuselage was largely due to the pioneer work of Mr. Anthony Fokker in Holland. The type of construction developed by him was used by American designers with various modifications to meet the needs of any particular design. The growth has been rapid and the metal fuselage has practically displaced the old wood and wire construction. The range of the adaptability of this type of construction is shown in Fig. 1. It is a fuselage for an airplane with a gross weight of 12,500 pounds. The fuselage is constructed mainly of alloy steel tubing with a circular cross-section. The compression members of the trusses are welded into the longitudinal members, and the various auxiliary parts,

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such as the tail skid, engine mount, and seats, are welded to these main structural members. Typical joints used at the panel points in fuselage construction are shown in Figs. 2 and 3. These joints replace a sheet metal fitting which was sawn out of a single sheet, wrapped around the joint, and fastened with bolts.

The welding of landing gears and control surfaces has become quite general and has done much to simplify their construction. One type of welded control surface is shown in Fig. 8. The tubing used for such parts is generally small in diameter, varying from ¼ to ½ inch, with a wall thickness of 0.021 to 0.065 inch.

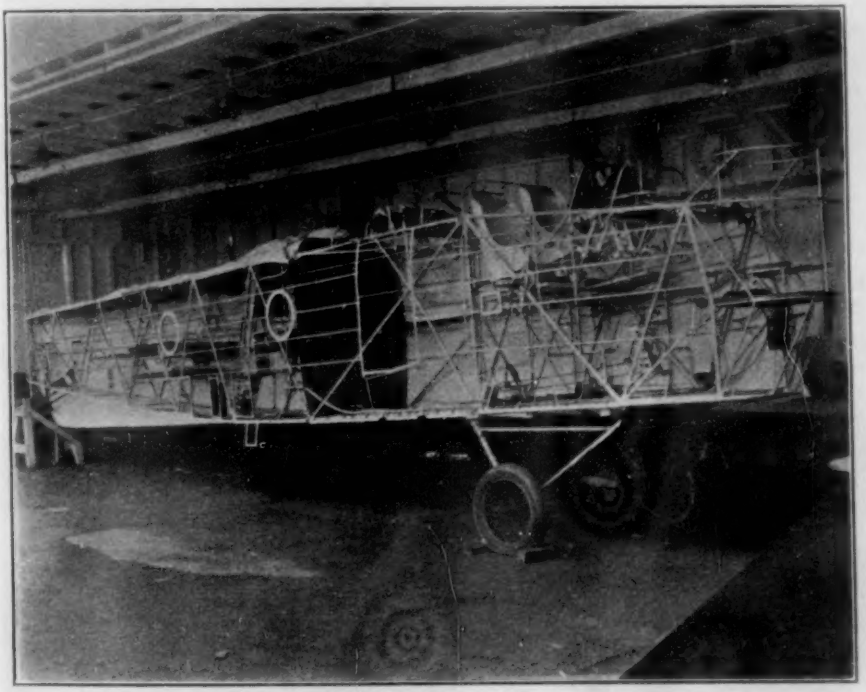

Fig. 1. Fuselage of 12,500 pound airplane

Welding tubing of this wall thickness requires skillful operators, but the resulting structure is exceedingly rigid and light in weight.

The use of welding in the wing structure has not advanced to the position of the welded fuselage on account of the difficulty of designing a steel structure which will compete with wood or light aluminum alloys on a strength-weight basis. With thick wing sections it is possible to use a truss construction for the wing beams as shown in Fig. 4. If the aluminum alloys could be welded without a serious loss in strength, the problem of a light metal wing structure would be simplified.

The materials used in these steel structures are plain carbon and alloy steels. Three and one-half per cent nickel steel has been

used to some extent, but is rapidly being replaced by chrome-molybdenum steel of the following analysis:

Carbon	0.25-0.35
Chromium	0.80-1.10
Manganese	0.40-0.60
Molybdenum	0.15-0.25

This steel has excellent weldability. The low and medium plain carbon steels are used to a greater extent in commercial aircraft than in military airplanes. Carbon steel tubing is entirely satisfactory for small airplanes, but the use of an alloy steel in the

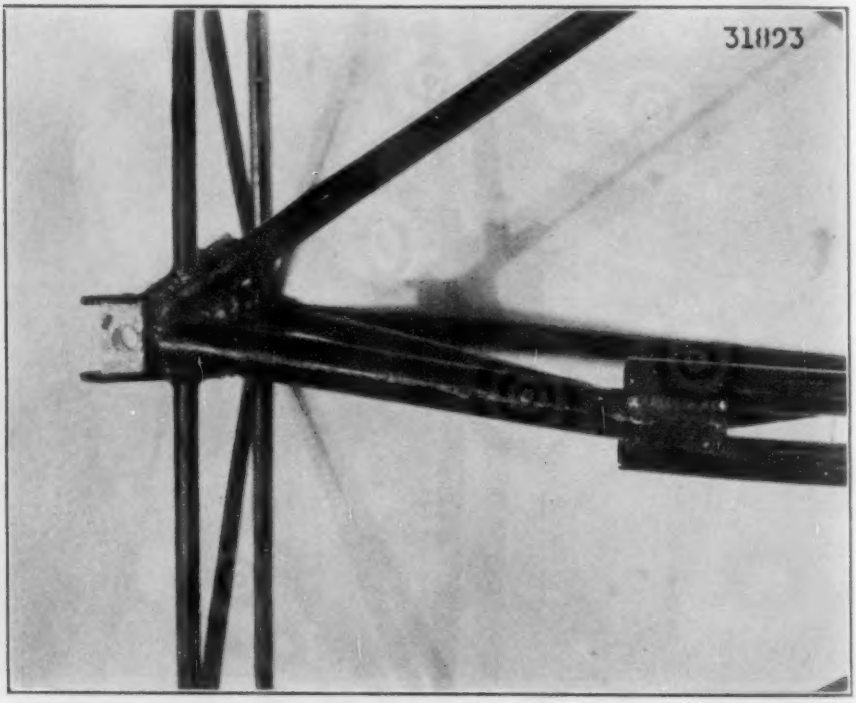

Fig. 2. Fuselage joint

larger types generally gives a reduction in weight, as the chrome-molybdenum tubing has a tensile strength of 95,000 pounds per square inch and a yield point of 60,000 pounds per square inch, whereas the carbon steel specification is 55,000 and 36,000 pounds per square inch, respectively. The higher tensile properties cannot always be used advantageously in small airplanes, since the property of stiffness is also important and the designer cannot reduce the wall thickness too much without making the structure fragile. The minimum thickness permitted by Air Corps specifications for main structural members is 0.035 inch. Thinner tubes, however, are used in control surfaces and for auxiliary

parts. The alloy steel has the further advantage that it is slightly air-hardening when cooling from the welding heat and therefore the tensile properties are not reduced to the same extent as with a carbon steel. Carbon steels with a range of from 0.20 to 0.35 have a similar advantage over the steels with a carbon content of less than 0.20 per cent, in that they retain more of their strength

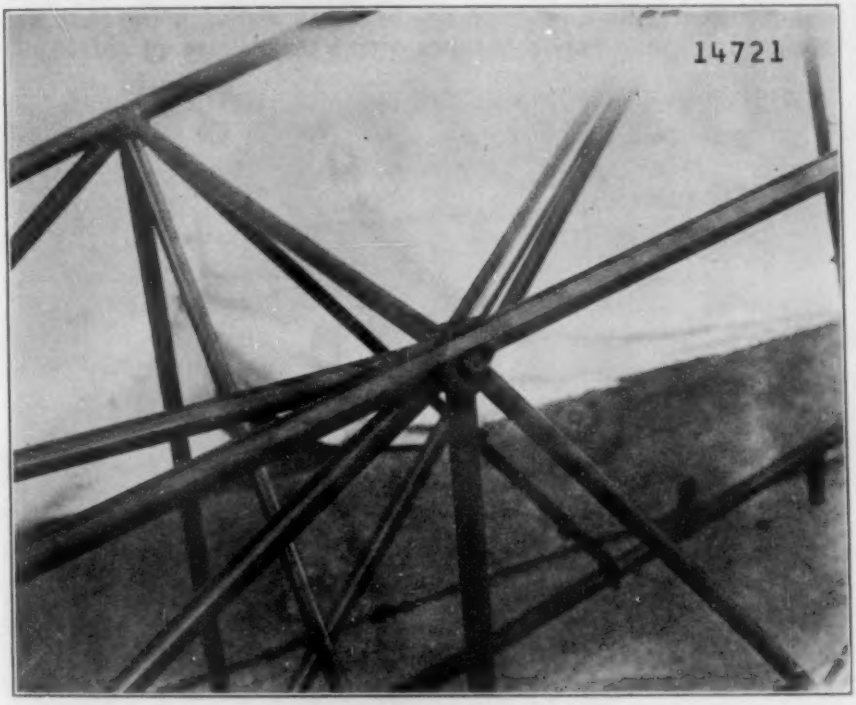

Fig. 3. Typical fuselage joint

TABLE I

Effect of Oxy-Acetylene Welding on Tensile Properties of Seamless Steel Tubing

Chemical Composition:						
Carbon	0.11 to 0.15		0.23 to 0.29		0.28 to 0.35	
Manganese	0.30 to 0.60		0.30 to 0.60		0.30 to 0.60	
Chromium	.....		.....		0.90 to 1.00	
Molybdenum ...	.....		.....		0.15 to 0.25	
	Unwelded	Welded	Unwelded	Welded	Unwelded	Welded
Tensile strength, lb./sq. in.	54,000	44,000	60,000	56,000	98,000	96,000
Yield Point, lb./sq. in. ...	34,000	22,000	38,000	35,000	75,000	72,000
Elongation in 2 in., per cent.	40	9*	25	8*	12	7*

*Low elongation due to change of section on account of welded seams.

The above results of the tensile test are the average of several obtained on specimens in the range of chemical composition indicated and varying in size from 3/4 to 1¼ inches outside diameter and 0.028 to 0.093 inch in wall thickness.

after welding. The results of tests of low carbon, medium carbon, and chrome-molybdenum steels are given in Table I. The loss is considerable for a cold-worked, low carbon steel and almost negligible for an air-hardening, normalized steel. The uniformity of the alloy steel tubing is also an important point, as the designer can be practically assured that the minimum physical properties specified will be obtained on every tube. In the case of commercial carbon steel tubing, the range in tensile strength and hardness is quite large, and very soft tubes with a tensile strength of 40,000

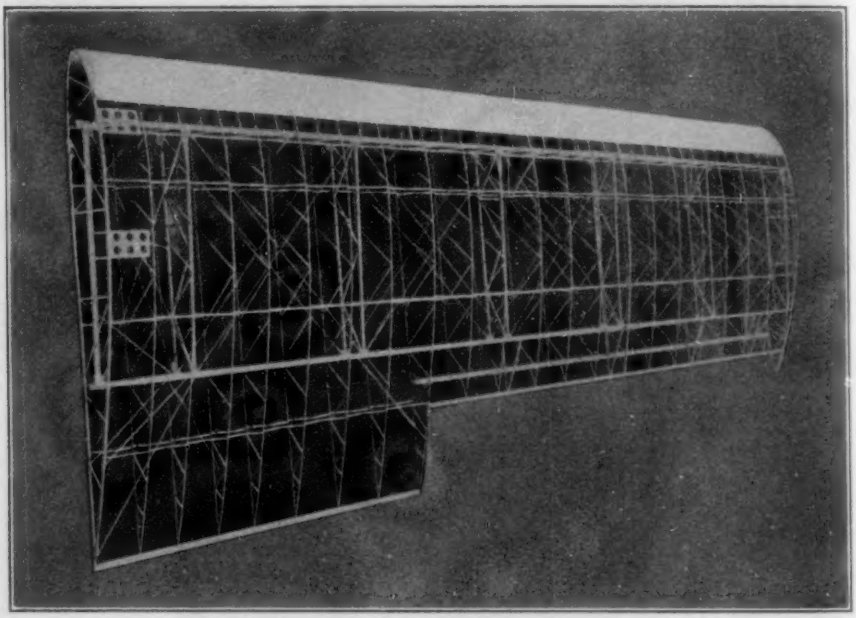

Fig. 4. Welded steel wing construction

pounds per square inch may be mixed with harder tubes having a tensile strength of from 60,000 to 80,000 pounds per square inch.

There are no established rules for the design of welded joints which are directly applicable to aircraft. The Air Corps has published a few for the assistance of designers which are based on the results of tests and service requirements. A reduction of 15,000 pounds per square inch in the tensile strength of a chrome-molybdenum steel has an ultimate strength of 95,000 pounds per square inch is recommended as a conservative figure for a straight butt weld. If the joint has a fish tail form or is reinforced by gusset plates, the value may be increased and designs have been approved in which an allowable stress of 95,000 pounds per square inch has been used in calculations.

The design of cluster joints must be carefully made to avoid too much over-lapping of welds. A rule has been adopted limiting

the number of tubes to six for any single cluster when the allowable stress of 80,000 pounds per square inch previously referred to is used. In case more tubes center the cluster the value should be reduced to 60,000 pounds per square inch for all tubes. A cluster of ten tubes is shown in Fig. 5. The amount of welding required to complete this joint has practically socketed the tubes in a casting formed by the fused welding rod. There are two tubes in this joint which were welded into it by building up a new seam over a previous weld. This is not good practice. Another example of this is shown in Fig. 6. The fitting has been welded directly to a seam formed by a previous weld. This design also has the objectionable feature that the section in which the weld is made is the section with the highest stresses due to bending

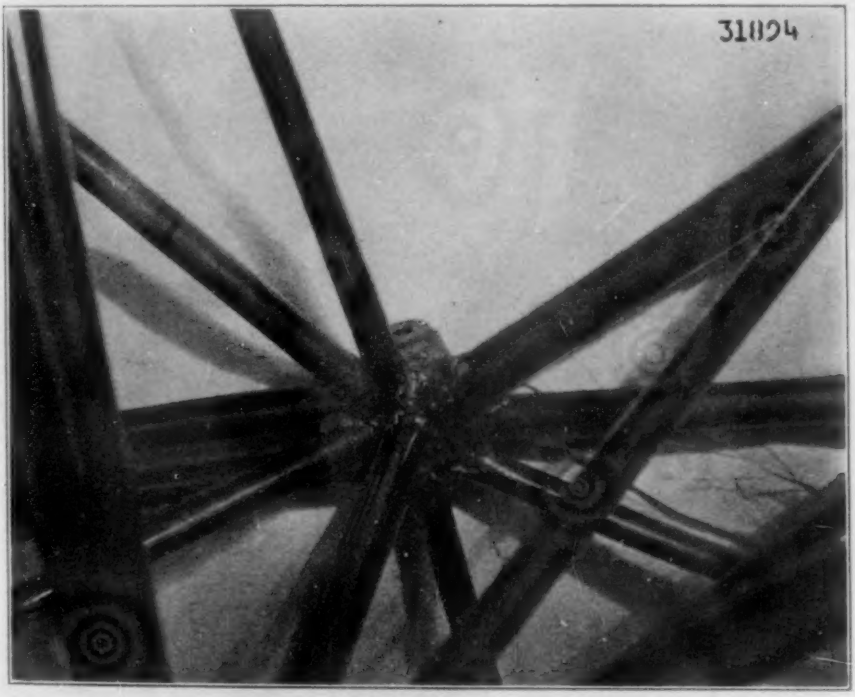

Fig. 5. A cluster with ten tubes

caused by a side load on the lugs. Welded joints have low ductility and should not be used to support a transverse load unless they are reinforced. In this case satisfactory reinforcement could be obtained by wrapping the "U" fitting around the tube or slotting the tube and extending the lugs and welding them to the wall.

A practice permitted in the construction of aircraft which would probably be considered questionable by many metallurgists is the welding of material after heat treatment and its use with-

out any reheat treatment. Sheet steel and tubular portions of assemblies are heat treated by quenching and drawing to a tensile strength of from 125,000 to 150,000 pounds per square inch and then welded to similar heat treated or unheat treated parts. The design of the section or area of the part not affected by the heat of the welding torch is based on the physical properties of the quenched and drawn steel, whereas the allowable stress of the portion affected by welding is based on the properties of the normalized steel. The area affected by the heat of welding is generally assumed for thin material to extend a quarter of an inch beyond the seam. This practice immediately opens up a wide field for the use of welding, as high strength heat treated lugs

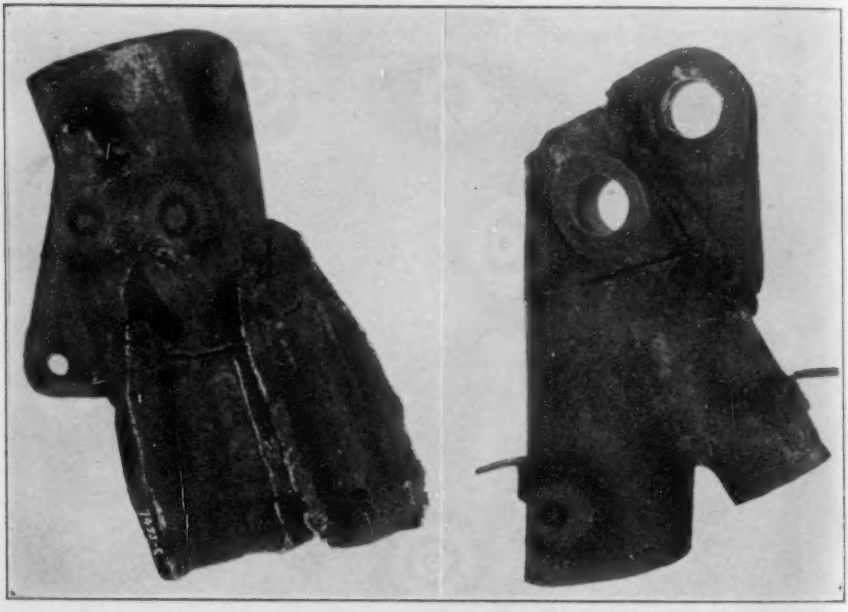

Fig. 6. Broken landing gear fitting. The break is thru the welded seam. The crack perpendicular to the axis of the right hand figure is a saw cut

can be welded directly to a steel tube structure in locations where the heat treatment after welding would be impracticable, and yet the lug can be reduced in cross-section and weight.

The construction and interchangeability of welded structures are facilitated by the use of jigs. Several types have been developed for this purpose, some of which are quite elaborate. A jig for assembling a fuselage is shown in Fig. 7. This jig was designed for the construction of several sizes and could be much simplified if production were limited to a single design. The longer ones are welded into the tail post and then the vertical and horizontal members are tied in, working from the rear end so that the cumulative expansion can be adjusted at the forward end. A jig for a tail unit is shown in Fig. 8.

The testing of any new type of construction for airplanes is very thorough. No exception has been made in the case of the welded structures. The test of a fuselage by means of dead weights is shown in Fig 9. The fuselage is supported in a test jig by means of the wing attachment fittings. Bags filled with shot are distributed over the structure until each member is sub-

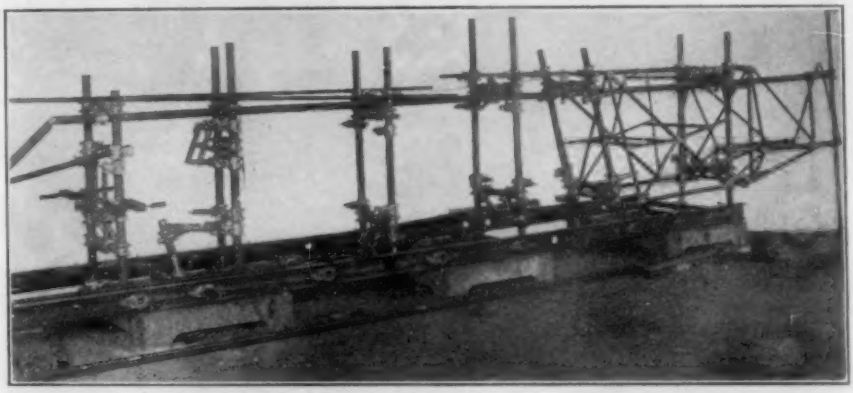

Fig. 7. Universal jig for construction of welded fuselage

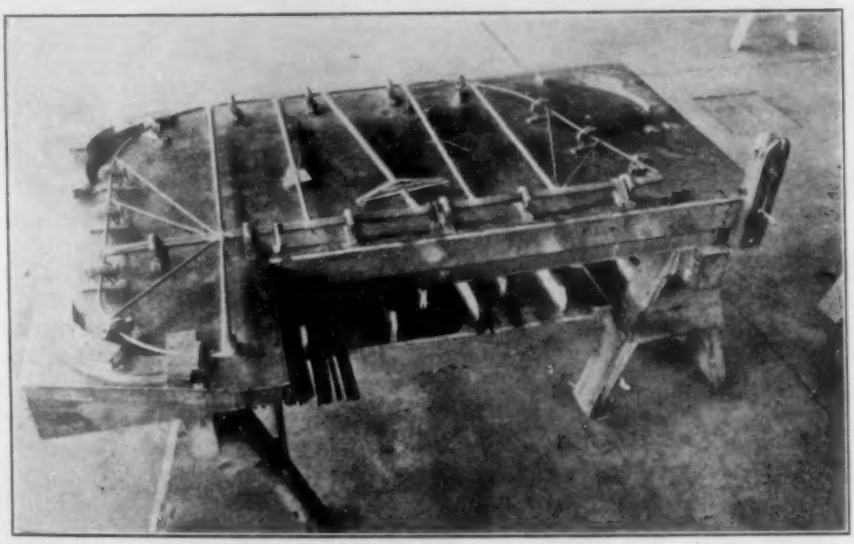

Fig. 8. Jig for control surfaces

jected to the worst load that will be imposed upon it during a critical maneuver, such as flattening out for a dive, multiplied by an arbitrary factor of safety selected according to the type of service for which the airplane is designed. Even under this severe test a weld seldom fails. A typical failure is shown in Fig. 9, which has resulted from the collapse of a compression tube acting

as a column. The failure is at a distance from the weld and has not been influenced in any way by the welding.

The landing chassis is subjected to not only a static test, but also a dynamic test. This test is made by attaching the gear to a

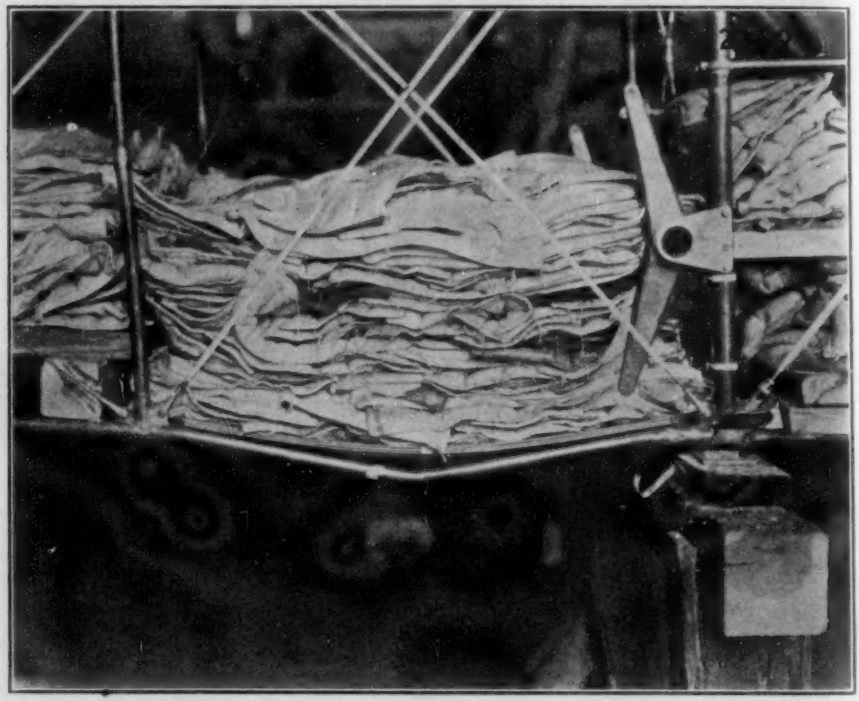

Fig. 9. Typical failure of welded truss. Compression member fails as a long column

fuselage or a heavy frame and permitting it to drop vertically on an inclined surface. Fig. 10 shows the results of such tests on a split type of landing gear. The tubes have failed in bending or by tension and bending. It should be noted, however, that the tension failure is at a distance from the joint and cannot be classed as due to a defective weld. A dynamic test of this nature subjects the weld to an impact load under which welds are generally considered to be weaker than some other types of joints.

Unit parts of an assembly are tested in specially designed jigs in the laboratory before the design is approved. A jig used for testing wing beams was shown in a previous photograph. A special apparatus for testing wing ribs is shown in Fig. 11. A system of levers distributes the load over the span, simulating the load to which it would be subjected under flying conditions. This particular rib had a 192-inch span and was built up of small, thin walled tubes welded at the joints.

Extensive surveys have been made of structures selected at random from a lot manufactured on a production basis without

any knowledge on the part of the builder that they were to be used for test purposes. The results obtained on the electrically welded, medium carbon steel fuselage are shown in Fig. 12 and Table II. Several joints were cut from a fuselage and pulled in

TABLE II

Tensile Stresses Developed in Welded Joints

Number	1	2	3	4	5	6	7
Diameter of tube, in.....	1.0	1.03	0.750	0.750	1.125	1.125	1.40
Wall thickness, in.....	0.037	0.030	0.035	0.035	0.047	0.049	0.064
Ultimate tensile strength, lb. per sq. in.....	70,500	68,000	60,520	68,430	66,510	72,800	58,400
Number	8	9*	10	11	12	13	14
Diameter of tube, in.....	1.250	1.50	1.375	1.750	1.660	1.375	1.375
Wall thickness, in.....	0.064	0.058	0.051	0.059	0.060	0.052	0.051
Ultimate tensile strength, lb. per sq. in.....	74,400	46,250	70,220	61,700	62,390	71,300	62,900

Tensile Tests on Fittings

	A	B	C	D
Maximum load on fitting at failure, lb.....	10,000	10,270	11,120	10,330

Fittings designed for two wires with an ultimate breaking load of 4100 pounds each.

*This tube was found to be a low carbon tube with a low tensile strength. The fracture in testing the joint occurred in the original tube four inches from the weld.

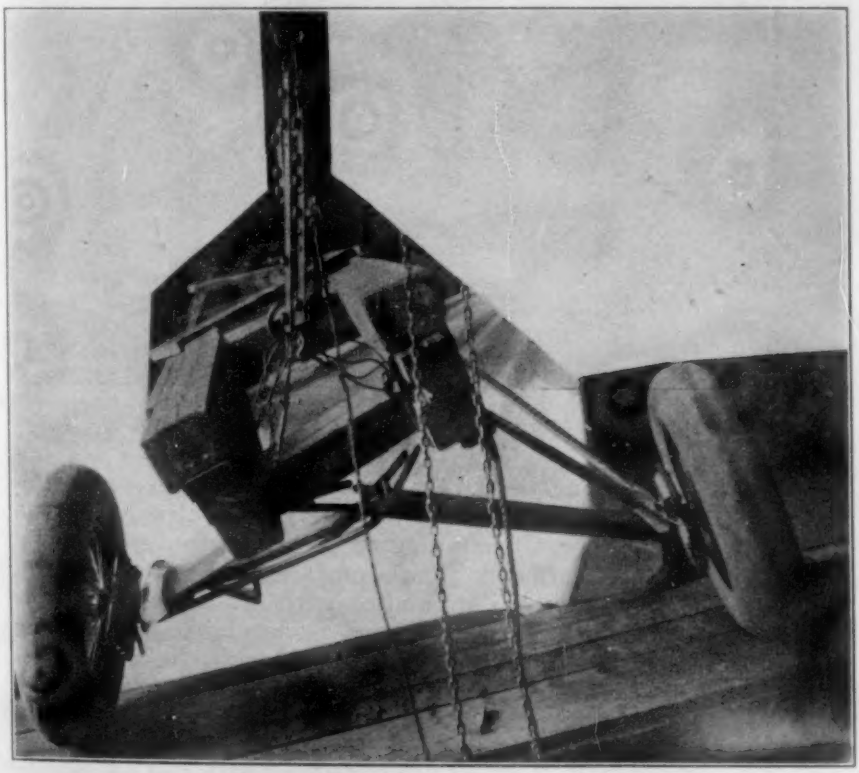

Fig. 10. Failure of split type landing chassis during impact test

a tension machine. Special fixtures were made up as indicated in order to simulate the loads which would be encountered in service. A study of this nature is quite valuable, as it represents a check not only on the design but also on the workmanship.

One of the outstanding advantages of a welded structure is the ease of repair and maintenance. It has been the experience of the Air Corps and of private commercial organizations that not only are welded steel structures more durable than the wooden structures, but they are also much easier to repair and keep in flying condition. The repairs should be made, however, with due

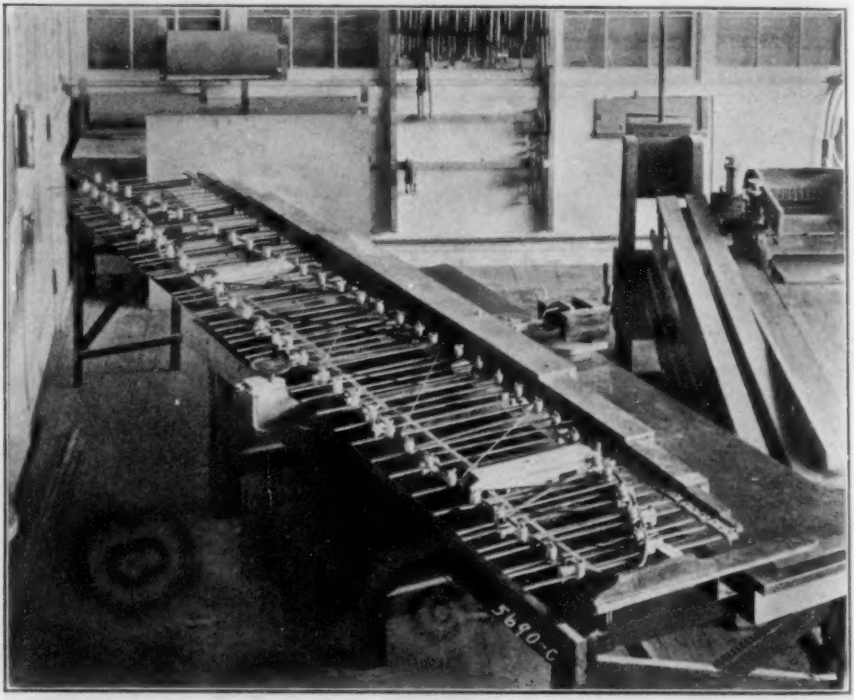

Fig. 11. Apparatus for test of wing rib showing welded tubular rib in place. Failure at 2000 pounds

consideration of the function of the member and its previous metallurgical history. There are certain parts of the airplane which depend for their proper functioning on the strength developed by cold-work or heat treatment. These parts should not be welded. Under this classification are streamline wires, cables, and tubular members which have been heat treated to develop a high tensile strength. Brazed or soldered joints should never be welded, as these non-ferrous metals form a brittle alloy with the fused steel or introduce impurities which contaminate the weld and produce blowholes and defective joints. Fig. 13 is a microphotograph of a joint showing the effect of welding a fitting which had previously

been brazed. There is practically no bond between the fused rod and the steel. The alloy formed by the fusion of solder and fused welding rod is shown in the microphotograph (Fig. 13). The alloy has a martensitic structure which is very brittle, as denoted by the cracks extending into the fused zone.

Splices should not be made in structural members such as longerons, spars, and interplane struts which are subject to direct tension or bending stresses unless the joint is reinforced by riveting, pinning, or telescoping. Where fish tail welded joints are used on tubes, the included angle should be approximately 60 degrees. The use of an oxy-acetylene flame or an electric arc to spot weld in lieu of rivets is not good practice unless the hole is sufficiently

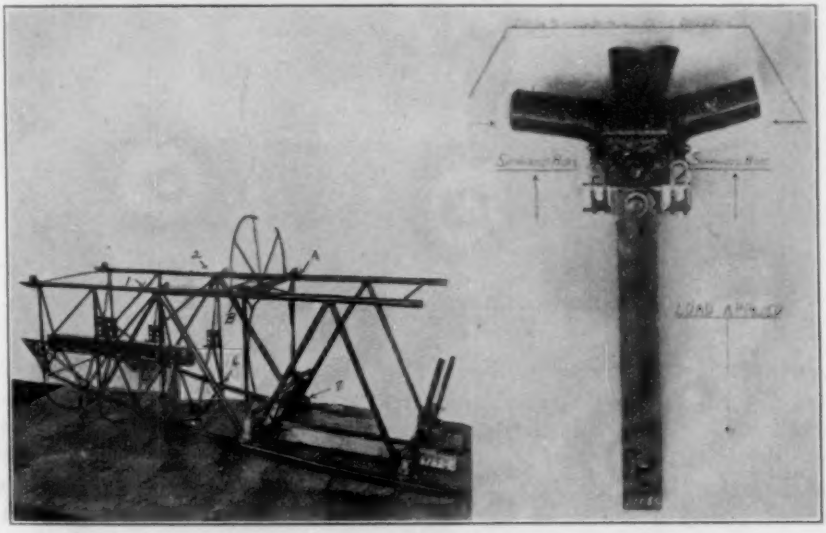

Fig. 12. Front section of electrically welded fuselage

Fig. 12a. Method of holding lugs A, B, C and D for tension tests. The failure was due to tearing out of the wall of the tube, probably influenced by method of support

large so that the conduction of heat is not too rapid to permit a proper fusion of the edges of the hole. For example, if an attempt is made to fasten together two telescoped tubes by drilling a small hole through the outside tube and fusing the edge of the hole to the inner tube, the heat is conducted away so rapidly by the inner tube that fusion does not take place. If the hole has a diameter of ½ in. or greater a satisfactory weld can be made.

Misalignment of tubular structures during welding, due to contraction or expansion caused by the heat of the torch, can be prevented by using wood braces with notches in the end to hold the tube in place.

The metal airplane is unquestionably a safer vehicle for transportation than the wood and fabric airplane. In case of a crash

the fire hazard is reduced and the danger from flying splinters and collapse of the structure is lessened.

The Army Air Corps made a series of crash tests on airplane fuselages to determine the effect of various safety devices in pre-

Fig. 13. Microstructure showing tin-iron alloy formed by contamination of welding fused metal with solder

venting fires after crashing. The fuselages were run down a sloping runway with the engine running and crashed into a concrete abutment. Photographs of these crashes also illustrated the advantage of metal construction in preventing the collapse of the structure. In the wooden structure the longerons and struts splintered. In the welded steel body the tubes bend and twist but do not splinter.

Welding Saves Steel, but Costs More

By JAMES H. EDWARDS†

Welding of parts of structural steel is no longer a process confined to repair of broken parts; it has become an industry, and there are plants that do welding exclusively. Structural fabricators have been somewhat conservative, because of an inborn prejudice against welding, and because the failure of an engineering structure would jeopardize life and property. While the time has not yet come to change completely from rivets to welds, fabricators could with safety and economy make use of welding in many ways in the ordinary run of fabricated steel.

Some completed welded structures have been erected, by parties

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for their own use, and by manufacturers and developers of welding apparatus. An all-welded 5-story shop building has recently been erected at Sharon, Pa., for the Westinghouse Electric & Mfg. Co. As this is probably the outstanding example up to the present

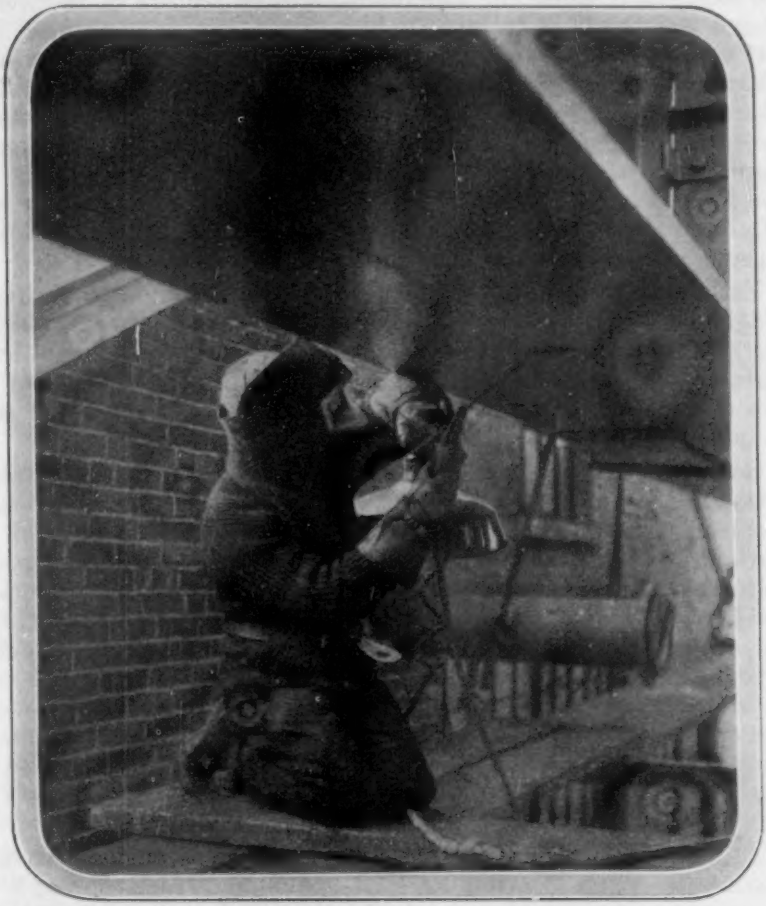

Fig. 1. Welding splice plate to girder; an overhead job

time of welded building construction, a description will be given of its design, fabrication, erection and cost.

The structure is a 5-story shop, 70 by 200 ft., with eleven 20-foot panels longitudinally, and three aisles transversely. In the lower story, one column is omitted for one floor to accommodate a runway for a traveling crane. The floors are of wood construction and carry a live load of 300 pounds per square foot.

The building was designed as a standard riveted type. The steel skeleton frame consisted of solid-rolled columns, and the floor framing of rolled beams, except the girders supporting the columns, above the crane runway, which were riveted plate and angle

girders. All floor supports were figured as simple beams or girders supported at the ends, carrying into the columns only vertical reactions.

A design was made for a welded structure to fulfill the same purpose and conditions. The distinguishing feature of the welded design was the floor framing, where advantage was taken of fixed end condition of beams and girders; these being figured as continuous members in flexure with a theoretical increase in load capacity of 50 per cent. In place of solid-rolled column sections, American Bridge Co. constant dimension plate and angle columns were used, so as to make beams framing between columns one length as far as possible. The beams were milled to length to obtain proper welding clearance, so the duplication was advantageous to both mill and fabricating shop.

Estimates of weight of steel of the two designs indicated a weight of 885 tons for riveted, and 790 tons for welded design, the saving being in the floor framing girders due to continuity feature heretofore mentioned. The cost estimates for steel of the two designs, using welded costs given by the Westinghouse company, were not far apart.

Being desirous to promote the welding of structural steel along rational lines, that is, by cooperation of welding apparatus manufacturers and fabricators, the American Bridge Co. undertook the work on the basis that the steel would be furnished at a fixed pound price for all material and work, except such material, apparatus and labor as were directly connected with the actual welding; that the customer would furnish the welding machines and welding wire and facilities for training welders; that all design and making of welds would be under the direct guidance of the customer's engineers and inspectors; and that the welding was to be done on a cost basis, the cost limited to an amount that would not make the total for steel erected exceed the estimated cost of the riveted design.

The welding equipment, furnished by the customer, consisted of a semi-automatic continuous fillet machine, which perhaps because it was more or less in its experimental stage, did not seem suitable for the work. One direct-current motor generator set built for two operators was used to some advantage, but did not seem to shop men as suitable for this class of welding as the single portable motor generator sets, 11 of which were supplied the shop. These machines were mounted on wheels, could be easily moved to the work, and their operation readily controlled. The plain material went through the standard operations for laying out for shearing, shearing and straightening, and for punching holes required for field bolts for erection. All the material had to be straightened to a closer tolerance than is customary for riveted work, and the edges of all plates were planed and the ends of beams and girders faced so as to maintain the clearance demanded by the welding.

This clearance was a maximum of 3/16-inch and was outside the standard mill tolerance for commercial structural shapes. From the drawings wooden strip pole templets were made for indicating position and extent of welds.

The bulk of the welding, both in shop and field, was due to the design requirement of continuity of fixed end connections. In order to carry the stress across the main floor girders from ends of joists, heavy bars were welded on inside of bottom flange of girder beams. This detail required special planing and leveling.

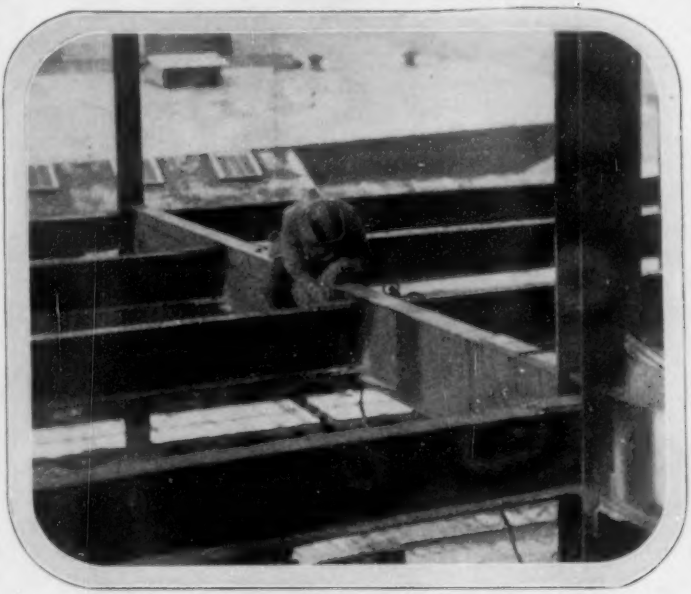

Fig. 2. Welding continuity plate which connects header beam to intermediate beam, also column connection

The welding was difficult and large in quantity of deposited metal, with consequent contraction and expansion difficulties that were costly.

After the shop work was finished and before shipment the steel was given a coat of oil. Paint should not be used when material is to be subsequently welded.

The field erection was handled in the usual manner with a locomotive crane on track placed in center of building. Each cross bent or frame was erected full height from base to roof as the crane was moved away from the raised portion. Some holes were provided in the connections to hold the material in place, but they were not enough to bring the members in true line. To plumb the skeleton and hold it wire rope guys were required from top to bottom at each cross bent and along each row of columns lengthwise for two of the bays.

More guys were used than ordinarily for a riveted structure,

and more careful alignment and adjustment was necessary to hold and maintain welding clearances.

Prior to the starting of field erection, the foreman and the men who were to have charge of welders, were given a course of instruction at the Westinghouse welding school, also at the building site a school was established to train men taken from the bridge erection forces. Fifteen men were thus trained and tested, but only seven lasted through the job. The younger men were more adaptable and made steadier welders. As it did not seem feasible to educate old bridgemen as welders, it was decided to try out professional welders. These were first tested by making welds on scrap material before being put on the work.

All the field electric equipment was supplied, installed and maintained by the Westinghouse company. It consisted of one- six-unit and nine single-unit motor generator sets. The three-unit machine was used for training and demonstration exclusively. The maximum number of welders was 15, the average working force was ten. It was estimated that four gangs of riveters, 16 men, could have riveted the work in the same time as it was welded. The value of the equipment used for field welding is estimated at about $16,000, while that for riveting would be about $5,000 or $6,000.

Aside from the difficulty in plumbing the frame and holding it in proper position by use of wire guys, instead of many drift pins in holes, the protection of the eyes of welders by shields and helmets, and the precautions necessary to avoid fire from sparks that might fall on welders' clothing or inflammable material nearby, there were no unusual precautions other than those met on other field jobs. The position of welding, as far as possible, was arranged so that the metal could be deposited either on a horizontal or vertical surface, with the operator in a workable attitude. Overhead welding should be avoided. In some detail connections this was necessary such as batten plates on bottom of plate girders.

The amount of welding done in the shop, taking as a basis of measurement 100 in. of single run 5/16-in. to 3/8-in. fillet, was approximately 244,000 lineal inches, using 11,700 pounds of 3/16-in. by 24-in. welding wire electrodes, and the cost was $4.18 per 100 lineal inches. In the field, 129,500 lineal inches were welded, using 4882 pounds of 16 5/32-in. welding wire, and the cost was about $8.00 per 100 lineal inches. The waste or loss of welding wire was 25 to 30 per cent and the weight of wire consumed ran about 1 per cent of the weight of the structural steel.

By comparing the actual cost of this welded structure with what a riveted one might be expected to cost, we find that there was a saving in material, due to design, of about 95 tons or 11 per cent; the template making was a trifle less for welded; the shearing, marking, punching and finishing would be about 10 per cent less for welded, the assembling of parts for welding about 100 per cent more for welded, and the welding in the shop not including the use

of electrical equipment shows a cost four times that of shop riveting. The raising of steel in the field, due to extra guying for alignment, was increased about 10 per cent and the field welding cost, not including the installation and use of electrical equipment, current and training of welders, was about the same as the riveting would cost. Prevailing shop and field labor rates were paid. Standard overhead expenses are included in the costs. After deducting the cost of training welders and making due allowance for other items that were included in this first job, and would disappear if shop were organized for welding, the additional cost of welded structure would be about $10 per ton, or about $8000. The material saved by welded design was 95 tons at a cost of about $3800, showing an excess cost of $4200 over a riveted structure, not including use and maintenance of electrical equipment, welding wire and cost of training school.

Estimates, based on unit costs determined on this work, indicate that the continuity feature of the design as a whole cost more than the material saved, besides introducing into the design and fabrication some complicated and possibly undesirable features. Continuous or fixed end support members have their place in structures, but before being used to any great extent all engineering and cost features should be carefully weighed.

Based on the experience gained from this work it would seem that the all-welded skeleton structure is not the most economic one. It is possible that some parts of a structure might be welded to advantage.

By the fusion welding process joints can be made as strong as the base metal, and the full gross section of a tension member can be used, with no deduction for holes as when rivets are used. Due to the greater stiffness of end connections, and the ease with which component parts can be more rigidly held together, welded details of compression members increase their efficiency. By taking advantage of these favorable factors, and with the added advantage that will obtain when sections more suited to welding are rolled, there may be some saving in material that will offset the extra cost of welding.

Where exising structures require strengthening because of increased loading, material can be added more advantageously by welding than by the expensive method of drilling holes and driving rivets in awkward field positions; also when additions are made to structures, welded connections can be well and cheaply made with a minimum disturbance of walls and exposure of occupants. Welding can be used to supplement riveting and will eventually find its economical place.

Resistance Welding*

Instruction for Beginners in the Operation of Resistance Welders

In the discussion of resistance welding it is assumed that the operator, whether a young man or a young woman, is a novice in the art of welding, and, therefore, does not know the basic underlying principles of this method of welding.

Basic Principles of Resistance Welding.—The art of resistance welding was discovered accidentally by Prof. Elihu Thompson in Philadelphia, in 1885. While experimenting with a spark coil operated from a bank of batteries he accidentally welded two steel rods of about ¼-in. diameter. Professor Thompson at once realized that here was a new scientific fact that could be utilized commercially. He immediately began to extend his experiments and soon built the first resistance welder which was known as the Jews Harp type. It now reposes in an honored place in the Museum of Antique Instruments and Electrical Machines at the plant of the General Electric Company, Lynn, Mass.

Up to this time only soft iron and the mildest steels could be welded by the blacksmith's forge, and when welding steel it was always thought necessary to use borax or some other flux, in order to obtain a weld.

With the advent of this new discovery and the building of a resistance welder it was immediately found that all ferrous metals could be welded by the process; that all non-ferrous metals could be welded equally as well; that any ferrous metal could be welded to any non-ferrous metal. This was, undoubtedly, the greatest advance ever made at any one time in the art of joining together two metals of either like or unlike character.

For many years welding done on these electric resistance welders was confined to the butt welding process, which consisted of clamping the metals firmly in electrodes, bringing them together by means of pressure, applying the current and allowing the resistance to the current at the point between the two pieces to cause heating in compliance with the principle that the heating effect of an electric current is proportional to I^2R. (I is the current and R is the electrical resistance.) When the two pieces of metal became sufficiently hot at their juncture additional pressure was applied, which forced them together into one piece, having from 80 per cent to 90 per cent as much strength at the weld as the original base metal.

This earlier method utilized a very low secondary voltage and a very high secondary current, which was secured by means of a transformer built into the welding machine itself.

The question is often asked why direct current cannot be used for resistance welding. It can be on very small work, but since it cannot be transferred to different voltages like the alternating current it is not available for welding except to a very limited degrees.

*Compiled by the Educational Committee of the American Welding Society.

The "Flash" Weld.—Many years later it was discovered that by using a much higher secondary voltage and turning on the current before the work was brought together, that when the two pieces of work approached each other very closely a violent arcing occurred across the minute air gap, and since the electric arc produces the highest known temperature, approximately 7500 deg. Fahr., these minute arcs almost instantly heated the faces of the work to a molten condition, at which instant they were forced together with enormous pressure, thus making what has since been known as a "flash" weld.

The "flash" method has now almost entirely superseded the butt weld method. It gives a quicker, stronger weld, with less upset

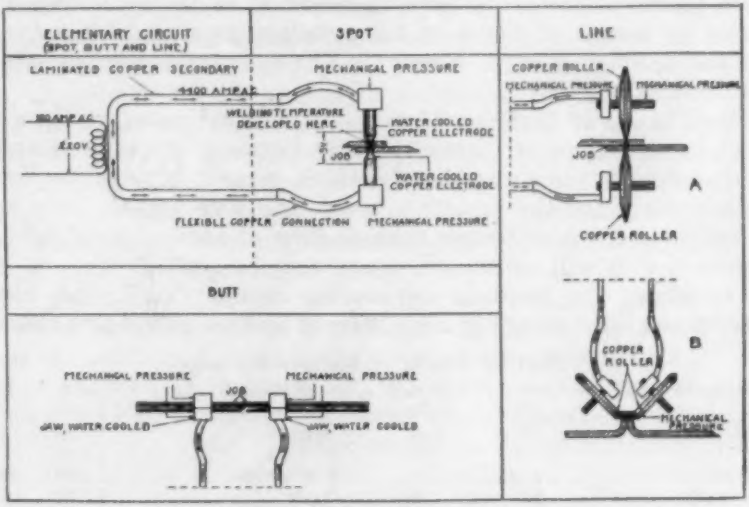

Fig. 1. Diagrams of circuits of butt, spot and seam welding machines

or burr to remove, and the weld usually has a strength considerably in excess of the base metal itself.

"Spot" Welding.—"Spot" welding is a branch of resistance welding and for the most part is used in place of riveting. It consists of the following operations: (1) The discharging of an enormous current, at fairly low voltage, through two or more pieces of sheet metal or bar stock; (2) of following up the discharge of current with sufficient pressure on the two or more pieces of metal so as to unite the molecules of the metal, and (3) of cutting off the current before the mechanical pressure is released, so as to prevent burning the die points.

The "spot" welding process is also used largely in the manufacture of wire goods, such as lamp shades, wire cloth, screening, netting, fencing, and an endless variety of objects and utensils for various uses.

"Seam" Welding.—Another branch of the resistance process is known as "seam" welding, which consists of passing two or more

metal sheets, or bars, between the rollers of a seam welder. The electric current passing from roller to roller through the work heats up the parts to be joined in the nature of a "spot" welder and the mechanical pressure on the roller electrodes consummates the weld.

Tube Welding.—Still another type of resistance welding consists of tube welding, whereby the stock is taken from the flat skelp, formed into a tube, passed through the welding machine, between concave electrodes, where it is instantly welded by a continuous butt welding process into tubes in various lengths up to 250 ft., at a speed of from 60 to 120 ft. per minute.

Broadly speaking, welding is the act of joining together two or more pieces of metal by causing cohesion of the molecules of the pieces by means of the high temperature produced by a forge, a gas flame, or an electric current. The resistance process uses the electric method only.

The Theory of Welding Metals.—Metals are most easily welded when in the stage of plasticity lying between the molten and the solid states, hence those metals which remain plastic the longest while cooling are the easiest to weld, and vice versa. In order to be weldable the metal must tend to flow at some critical temperature so that it will cohere when pressure is applied.

Therefore, the welding apprentice should familiarize himself with the melting points of the different metals, alloys and elements.

Melting Points of Various Elements

Element	Cent.	Fahr.	Element	Cent.	Fahr.
Tin	232	450	Silicon	1,420	2,588
Lead	327	621	Nickel	1,452	2,646
Zinc	419	787	Cobalt	1,480	2,696
Tellurium	452	846	Chromium	1,520	2,768
Antimony	630	1,166	Iron	1,530	2,786
Magnesium	651	1,204	Vanadium	1,720?	3,128?
Aluminum	659	1,218	Platinum	1,755	3,191
Silver	960	1,761	Molybdenum	2,500?	4,532?
Gold	1,063	1,945	Tungsten	3,000?	5,430?
Copper	1,083	1,981	Carbon	3,600?	6,510?
Manganese	1,260	2,300			

Besides familiarizing himself with the above table of melting points it would also be well for the welding apprentice to learn to judge approximate temperatures from the heat colors. The following table is approximately correct for iron only and cannot be used for other metals or alloys:

Heat Colors for Iron

Colors	Cent.	Fahr.	Colors	Cent.	Fahr.
1. Faint Red	482	900	7. Salmon	899	1,650
2. Blood Red	566	1,050	8. Orange	941	1,725
3. Dark Cherry	635	1,175	9. Lemon	996	1,825
4. Medium Cherry	677	1,250	10. Light Yellow	1,079	1,975
5. Cherry or Full Red	746	1,375	11. White	1,204	2,200
6. Bright Red	843	1,550			

The color scheme as a means of determining temperatures cannot be relied on implicitly, however, since welding temperatures

vary widely sometimes for the same elements or alloy. As for instance:

Wrought iron melts at	2,900 degrees, Fahr.
Malleable iron at	2,500 degrees, Fahr.
Cast iron at	2,400 degrees, Fahr.
Pure iron at	2,760 degrees, Fahr.
Likewise—	
Mild steel melts at	2,700 degrees, Fahr.
Medium steel at	2,600 degrees, Fahr.
Hard steel at	2,500 degrees, Fahr.

Best Welding Temperature.—The best welding temperature for most metals is usually about 100 deg. below their melting points, at which point they are in a plastic state. A few metals, however, such as lead or cast iron, do not become plastic until their melting temperatures are reached—hence they are very difficult to weld. Many metals must be welded almost instantly in order to secure the desired kind of welded joint. Such metals include copper, brass, aluminum, bronze and various other metals and alloys. The reason for this fact is that oxidation takes place in many of these metals or alloys if the heating is applied over any appreciable length of time, as for instance, in the case of copper and aluminum. In other cases of alloys, such as an ordinary commercial grade of brass, which consists of approximately 66 per cent copper and 34 per cent zinc, the ingredients of the alloys do not have the same melting point, and if the weld is not made practically instantly one or more of the elements will volatilize from the vicinity of the weld, leaving an entirely different substance at the point of weld.

As an example of the foregoing statement, in the case of brass, zinc melts at 778 deg. Fahr., whereas copper does not melt until it reaches 1981 deg. Fahr. Hence, it can easily be seen that, if any appreciable length of time is used in heating up the metal in the vicinity of the weld, the zinc will all volatilize and disappear in vapor form, leaving only a spongy oxidized copper at the point of weld. However, by making copper, brass and aluminum welds practically instantaneous, there is a sharp report like a pistol, and the weld is consummated without time for oxidation or volatilizaton of any of the constituent parts of the materials. In fact, the quicker any kind of weld is made in any metal the better and stronger the weld is likely to be. Hence, the present tendency in the field of resistance welding is to use larger capacity welders than formerly, thus making the weld more quickly. This procedure in turn gives a much larger daily production on the welder.

Power Required for Resistance Welding.—The following formula which was discovered by Woofter in 1919, gave a very close approximation of the rating of resistance welders in relation to the cross section of work they were capable of welding:

> "30 KVA applied for 20 seconds of time to weld 1 sq. in. of iron or steel, using 5000 lb. mechanical pressure to consummate the weld."

By this formula it will immediately be seen that if it were de-

sired to weld 1 sq. in. of steel or iron in 10 seconds it would require a 60 KVA welder, or vice versa, if the weld were made in 40 seconds it would require a 15 KVA welder.*

Now, suppose the welder desired to know the size of a welder required to weld a 2½-sq. in. of cross section. Applying the formula and multiplying the KVA by 2½ it follows that a 75 KVA welder would be necessary.

This formula was fairly accurate for resistance welders as designed at that period. At the present time, however, it would seem that with the present practice of manufacturers to use larger welders to increase their product, and since these welders also are

*KVA should be read Kilo-Volt-Amperes.

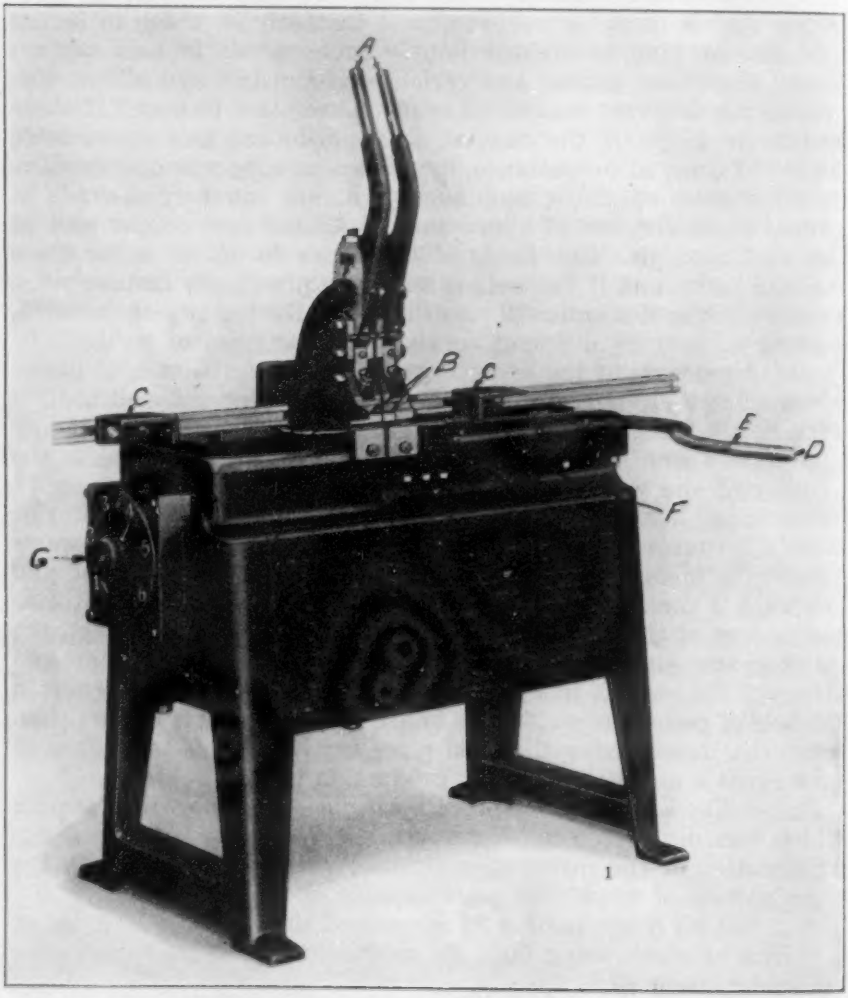

Fig. 2. Hand operated butt or flash welder

much more efficient in design than were those of 1919, that the formula should now be changed to read as follows:

"30 KVA applied for 10 seconds to 'flash' weld 1 sq. in. of iron or steel."

It should be noticed in the use of the formula that the amount of power required varies inversely with the time required to consummate the weld. That is to say, cutting the time of a weld in half will require twice as much power, while doubling the time requires but half as much power.

The mechanical pressure required is a function of the cross section and does not vary for the same elements under the same conditions. Varying the conditions, however, varies the amount of pressure, as for example, it takes from 50 to 100 per cent more mechanical pressure to "push up" a weld on drop forged parts than it does for cold rolled, cast or machinery steel.

A beginner on welding would probably be set to work on the simplest type of welder, which is hand-operated throughout and which is illustrated in Fig. No. 2.

The Hand-Operated Resistance Welding Machine.—In Fig. No. 2 it will be noted that there are two levers standing approximately upright at *A*. These levers clamp the work at *B* so as to insure a good electrical conductivity in the secondary circuit of the transformer and into and through the work, and also to prevent the burning of the dies.

On medium work, such as that having a ¾ sq. in. cross section or under, the clamping pressure is sufficient to hold the work against the mechanical pressure, which pushes up the weld at its completion. But, in order to relieve the clamps from continued strain and also to act as a guide and to make sure that the finished work will all be the same length, a set of adjustable work stops is provided as shown at *CC* in Fig. 2. These work stops may be set to take the lateral thrust and thus relieve the clamps from strain, and also to insure the work being uniform in length.

After the work is clamped, as noted above, the operator, if he is to make a butt weld, pulls the toggle lever at *D*, which forces the cold work together. He then presses a push button with his thumb, at *E* (not shown in the illustration) which turns on the electric current.

As the work heats to a plastic condition the operator gives a quick pull on the lever, which forces the clamps toward each other, and at the same time cuts off the current automatically at *F*, by means of an automatic cutout switch, which should always be set to cut off the current just before the final "push up" takes place. This automatic cutout prevents burning the weld.

If the operator is to make a "flash" weld, the work should be inserted as before, but the lever *A* is pushed back so that the work does not quite come together at the point to be welded, then the operator should first press the push button, which turns on the power and then start moving the lever *D* toward the left. When

the pieces of work are almost together the "flashing" or "arcing" begins and becomes more violent the faster the lever is moved.

The ordinary practice is to grasp the lever and pull it quickly and firmly to the left with one stroke, which completes the weld, the current being automatically cut off, as noted, for butt welding.

If the work to be done on the welder, shown in Fig. No. 2, is small in cross section, it is usually necessary to turn the regulator switch *G* until the indicator is opposite one of the lower points, as 1 or 2. Medium sized work would ordinarily be welded on switch points 3 or 4, while the maximum size or overload work would ordinarily require the regulator switch to be set on point 5 or 6.

The regulator switch *G* is connected to taps in the primary winding and varies the secondary voltage and at the same time the current flowing from a minimum flow on point 1, to a maximum flow on point 6.

It may be necessary from time to time to change the opening of the clamping jaws to suit different sizes of work. This change is made by loosening the lock nuts and adjusting screws in the levers, as shown at *H*.

There are many adjustments on a welder of this type and they are all very simple, as, for instance, the adjustment of the six point regular switch, the adjustment of the work stops, the adjustment of the clamping jaws, and last but not least, the adjustment of the automatic cutout switch. This latter adjustment is important since the successful character of the weld will depend largely on this automatic feature.

There is one other adjustment which it is sometimes necessary to make. It involves the moving of the right-hand platen toward the right or left so as to increase or decrease the opening between the dies. This adjustment is made in most welders by means of a turnbuckle at *J*.

In ordinary round stock the work should project out of the electrodes, a distance of from $\frac{5}{8}$ in. to one complete diameter of the stock. This applies to both pieces. In flat or bar stock the projection on each piece is usually from one and one-half times the thickness in fairly thick stock to four or five times the thickness in thin stock, such as saw blades. If there is no experienced welder on hand to instruct the operator he can determine the best length of projection to use on any particular job by a few minutes' experimentation.

When welding two pieces of dissimilar metals or alloys, it is often necessary to use different projections on the two pieces, as for instance, when welding mild steel on high speed or high carbon steel. The high carbon steel being harder and having a higher resistance requires a shorter projection beyond the electrode than the piece of mild steel to which it is to be welded. This relative projection is also a matter that the beginner, in order to be an efficient operator, should learn to determine for himself.

The Automatic Welder.—After the operator has become proficient on a hand-operated welder he is likely to be advanced to the

operation of an automatic welder, which may do the same work as the hand-operated welder on which he has been working, but which will do it three or four times as fast, thus bringing in a new factor, namely, that of the deftness and quickness of the eye and hand of the operator.

The automatic welder itself will take care of the clamping, projection, flashing, cutout of current, upset of weld, opening of jaws and return ready for the next operation, the only func-

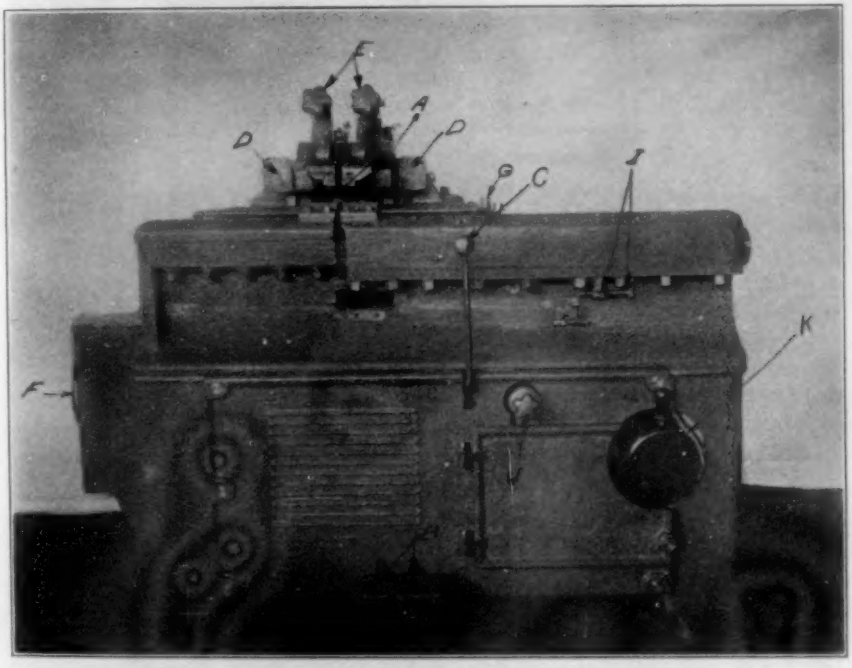

Fig. 3. Completely Automatic "Flash" or "Spot" Welder

tion of the operator being to insert the work, step on the treadle with his left foot, touch the lever with his right hand and the machine does the rest.

Such a welder might be similar to that shown in Fig. No. 3, which is an automatic rim welder for automobile rims, hoops, bands, etc., although it could be used just as well on straight work instead of being limited to circular work.

An automatic welder is usually motor or belt driven. The operator inserts the work as at *A*, steps on the two pedals at *B*, touches the lever *C* and the welder does the rest, even to the "kicking out" of the completed work by means of the plungers at *D*.

The operation of an automatic welder, when properly built, is so simple that even a girl can operate it almost immediately, with little previous training or experience. It is necessary, however, that the operator as soon as possible should learn to make the slight adjustments that might be necessary from time to time to take care of variations of stock or production output that might be required.

For instance, increasing the speed of the motor at *K* speeds up the entire train of operations, and the operator must also speed up his or her movements accordingly.

Screwing in the hand knobs at *E* sets the clamp for thinner stock

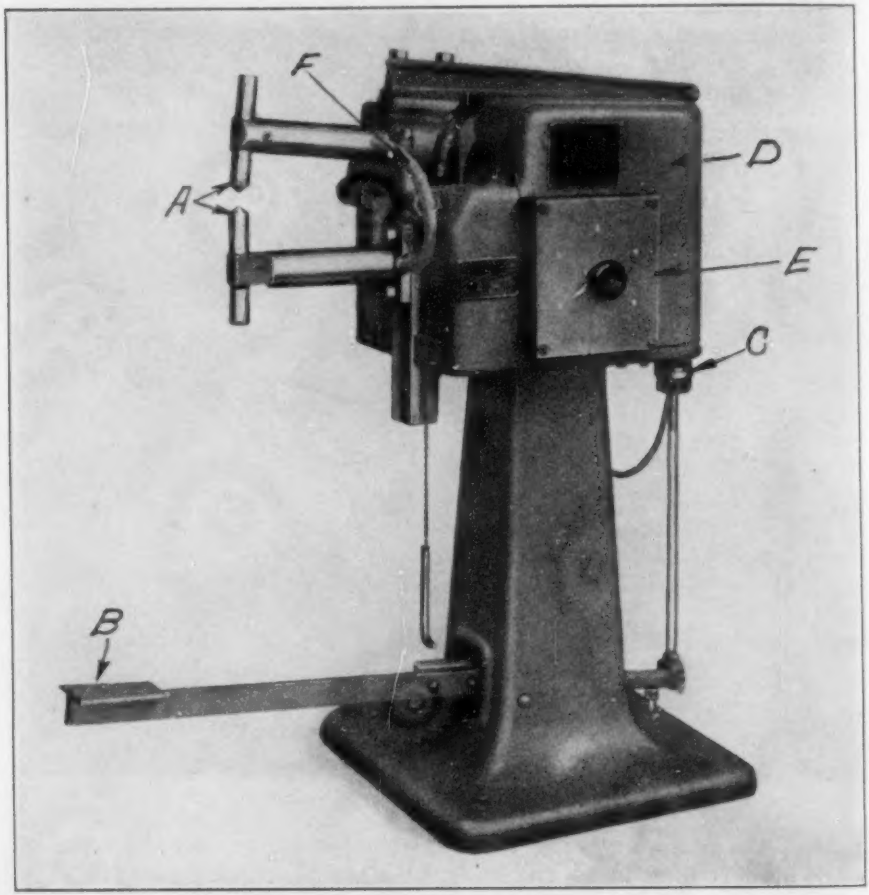

Fig. 4. Foot Operated "Spot" Welder

and vice versa. Stepping up the regulator switch at *F* gives a higher secondary voltage and increased current for larger and faster work. Turning the pin *G* varies the projection of the work by shifting the movable platen toward the right or left. Turning the handwheel *H* varies the amount of burnoff at point of projection, while turning the thumb screw and thumb nut at *I* changes the time of the automatic cut off of the current, and finally, the knurled wheel and hand knob at *J* varies the amount of upset at point of the weld.

In spot welding, while the majority of the welding machines now in operation are of the hand or foot operated type, the present trend of the trade is toward automatic spot welders, which practically

eliminate the human element except in the matter of the putting-in and taking-out of the work. In fact, some automatic welding machines have been so far developed that they include automatic loading and unloading hoppers, thus eliminating the operator entirely, except to start the machine going and to dump the work into the hopper.

The beginner, however, will undoubtedly be set to work on the hand or foot-operated welding machine—most likely on the foot-operated machine—and therefore the authors will first present and discuss the problems that will arise in operation of a foot-operated machine.

First of all, the work should be fairly clean, because rusty, painted or shellacked stock does not weld readily and it also burns the die points excessively.

Operators should first take into account the thickness or gage of the stock. It may be assumed that he is to "spot" weld work consisting of two pieces cut from No. 16 gauge stock. There is a vital relation between the gauge of the metal to be welded and the diameter of the die point. In fairly light gauge work, such as is under consideration, the diameter of the die points should be from 1½ to 2 times as great as the total thickness of the work being done. That is to say, on two No. 16 gauge sheets, which are approximately two 1/16-in. sheets, the die points should be from 3/16 in. to ¼ in. diameter. They should be not less than 3/16 in., otherwise they make too deep scars or indentures on the work. They should not be excessively large, since they will take too much power if the welder transformer is large, and if the welder transformer is small the large area will not be heated to a welding temperature.

Under continued use the diameter of the die points increases, since the copper of which they are made is being gradually worn away and the operator should learn to dress the die points quickly and accurately. There are two or three die dressing devices on the market which may be inserted between the die points in place of the work and by a few turns of the device the die points may be dressed without removing them from the horns of the welder.

The second problem of the operator will be the matter of the correct mechanical pressure to be applied at the instant of plasticity of the metal. It requires much greater mechanical pressure per square inch to make a good spot weld than to make a good resistance weld. This pressure runs in the neighborhood of 14,000 lb. per square inch for iron and steel. This great pressure is undoubtedly needed because of the relatively small heated area of metal and the support given it by the adjacent cold metal. This pressure is regulated by means of a coil spring between compression nuts on a vertical rod on the rear of the welder. By compressing the spring the pressure on the die points, hence on the work, will be increased, and vice versa.

A little experimenting on the part of the beginner will enable

him to determine when the pressure is right and the proper "spot" weld is being made.

The third problem of the operator will be to adjust the electric switch with regard to its cutting on and cutting off the electric

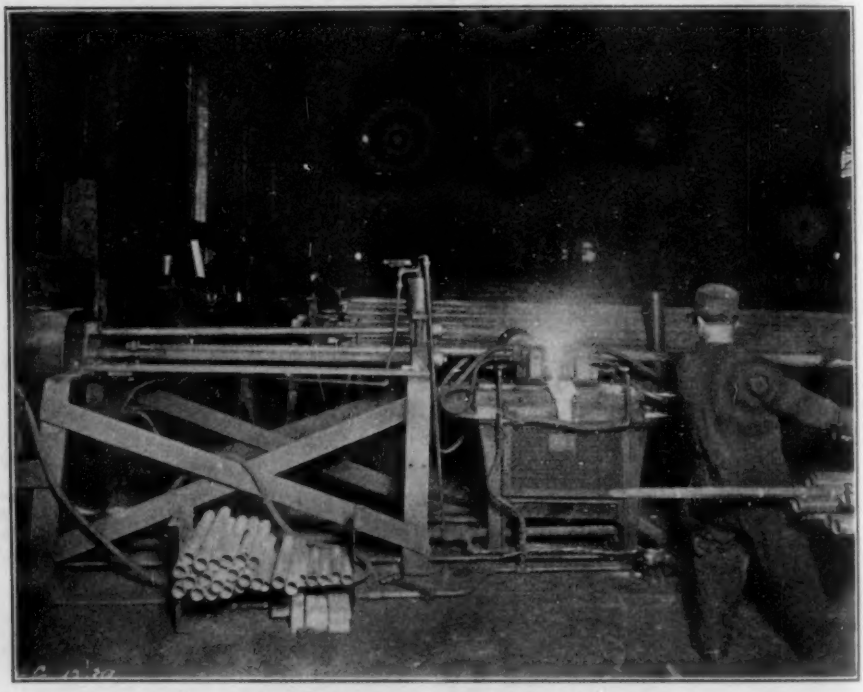

Fig. 5. Flue welder installation

current. This switch is located just above the spring in the rear of the welder, and when once set operates automatically with the foot lever.

The proper procedure in a "spot" weld is as follows:

1. The die points are caused to come together exerting mechanical pressure on the work.
2. The electric current is caused to flow and heats the work.
3. The plastic hot metal yields under the pressure, thus allowlowing a spring to automatically cut off the current.
4. The pressure is released from the finished weld.

If the current should come on before the mechanical pressure the die points would arc and "spit" and be burned. Likewise, if the mechanical pressure is released before the current is cut off the die points are burned in like manner, since they will draw an arc when leaving the work. Therefore, it is very essential to strictly observe the sequence of the four items enumerated above.

When welding iron, steel, brass and aluminum, the die points should be flat, but when welding galvanized stock the die points should be slightly oval, so that the current will break through first at the center of the spot, which volatilizes the zinc and drives it

out from under the die points, thus leaving bright, clean metal on which the spot is made.

Fig. No. 4 shows the simplest form of a foot-operated spot welder. The only automatic feature in it being the automatic electric switch to which reference was made.

On the "spot" welder, shown in Fig. No. 4, the die points are shown at *A*, the foot lever at *B*, the compression spring at *C*, the automatic electric switch (not shown in this view) is opposite to *D*. The regulator switch for adjusting the secondary voltage and the current is shown at *E*. The same rule will apply regarding the setting of the regulator switches for spot welders as has already been given for butt welders.

The horns of most "spot" welders, as well as the secondary circuit, are water cooled, the cooling ducts being connected by rubber hose, as shown at *F*. The operator should always be sure to turn on the water for cooling in the morning and shut it off before leaving his welder at night. This precaution is necessary for various reasons, but for two especial ones—

Fig. 6. Spot welding booths

1. If the water is left on a leak may develop during the night, which will saturate the primary winding and cause the coils to "short" when the current is thrown on next morning.
2. If water is left on in winter there is danger of freezing and bursting of pipes, or castings, which would put the welding machine temporarily out of operation until new parts were procured and installed.

When an operator is assigned to an automatic spot welder he will

find about the same problems of adjustment of current and pressure, as already noted on the automatic flash welder, and these should be observed.

It is not necessary to give explicit instructions regarding the operation of seam welders or tube welders. These two types of resistance welders are so highly specialized and run into so much money that the purchaser of such a welder usually sends an operator to the factory where the welder is being built to remain a week or two and become thoroughly familiar with the mechanical and electrical details of the welder and its operation.

Last, but not least, the operator should always take good care of his machine, keep it clean, well lubricated and accurately adjusted. This care is especially necessary in resistance welders where the "flash" method is used, since the "flash" which goes into the air, falls again in fine metallic particles covering the entire machine and everything else in the immediate vicinity. This dust and particles are known as slag, and the matter of dealing with slag is one of the hardest problems with which the manufacturer of welding machines has to deal. This slag is as bad an abrasive as emery dust and when allowed to get into the bearings or journals or any working parts of the welding machine it will ruin them in a very short time. Furthermore, this slag is a conductor and when allowed to pile up on various parts of the welding machine it often causes short circuits which result in "burn outs" of windings or insulation.

The operator should, therefore, use an air hose freely and at short intervals, to blow the slag out of the welder and especially out of the transformer and switches. By so doing he will help to insure satisfactory operation of the welder and the continuity of his job. The operator should take pride in the fact that he has been placed in charge of a high priced, highly specialized piece of electrical apparatus. Also he should feel the responsibility of the fact that the work he is turning out will be used in an automobile or truck or farming machinery, or in many other vital places where careless work on his part might cause loss of life or injury to his fellow beings. He should, therefore, feel sure that every weld he makes is beyond reproach and that it will stand the test of time and use.

APPENDIX A.

RULES AND REGULATIONS

The following rules and regulations affect the use of welding and are taken from the second edition of the Welding Encyclopedia. Welders are urged to familiarize themselves with these rules.

A. S. M. E. Boiler Code (1918 edition rules for the construction of stationary boilers and for allowable working pressures). (A. S. M. E. Boiler Code Committee, 29 West Thirty-ninth Street, New York, N. Y.).

Department of Commerce (Steamboat Service, Ocean and Coastwise as amended 1922). General rules and regulations prescribed by the Board of Supervising Inspectors Welding and Reinforcing by the Electric, Oxy-Acetylene or other processes. (Washington, D. C.)

Lloyd's Register of Shipping Rules. (17 Battery Place, New York, N. Y.)

Various State Rules.

When an operator is assigned to an automatic spot welder he will

Interstate Commerce Commission—Specifications for shipping containers. (Washington, D. C.)

American Railway Association (M. C. B.) Code of Rules. American Railway Association, (30 Vesey Street, New York, N. Y.)

Steam Boiler and Fly Wheel Service Bureau. Requirements for autogenous welding in insured boilers or other pressure vessels for new construction and repairs. (13 Park Row, New York, N. Y.)

Underwriter's Laboratories. Standards for construction of stationary acetylene generators, pressure regulators, blow pipes and fittings for oxy-acetylene welding and cutting systems (Chicago, Ill.)

National Board of Fire Underwriters—Regulations for the installation and operation of acetylene equipment. (Chicago, Ill.)

Standards for Testing Welds. American Welding Society, Bulletin No. 1. (New York, N. Y.)

Electric Arc Welding Apparatus. A. I. E. E. Standards. The American Institute of Electrical Engineers. (New York, N. Y.)

The Bend Test as Applied to Welded Coupons*

By W. B. MILLER†

It will be generally admitted that any test to evaluate the quality of a weld quickly and inexpensively is desirable. Welded coupons have often been tested by bending and measuring the angle of bend. This test usually reveals any lack of fusion, thus being a test of the welder. If the weld has been properly made, the test then becomes a rough measure of the inherent quality of the weld metal and the union of weld and base metals.

For some time, on account of its simplicity, our attention has been directed toward the bend test with the hope that it might possibly be standardized to the extent that it would yield quantitative data on the properties of weld metal. Most modern publications on "Materials of Construction" refer to the bend test as a rough and ready test of ductility, in all instances the angle of bend being taken as a measure of the ductility. According to Johnson's "Materials of Construction," the bend test is a more severe test of ductility than the tension test, but has not been so carefully standardized. Methods of starting and closing the bends vary considerably and herein lies the main cause for discrepancy in this test. Owing to the congestion of metal on the concave side of the bend and to restricted lateral expansion, the neutral axis of a specimen must approach nearer to the concave side as the angle of bend increases. Consequently the angle through which the specimen is bent without cracking forms a crude index of ductility. It is good practice in tests for comparative purposes to observe both the angle at first crack and at rupture. This reference from Johnson is the most complete I have found in English publications and it is interesting to note that the angle is always measured. We believe that other measurements yield more definite data and are applicable to any bend specimen, regardless of the method used in making the bend.

*To be presented before the Annual Fall Meeting of the A. W. S., Sept., 1927.

†Union Carbide & Carbon Research Laboratories, Inc., Long Island City, N. Y.

With this not very encouraging information from the literature we first started the bend testing of welded coupons on the Standard apparatus of the American Welding Society Bulletin No. 1 which consists of a ram and anvils, the ram thickness being varied with the specimen thickness, the contact edge having a radius of curvature equal to one-half the ram thickness, the radius of curvature of the contact portion of the anvils being 1 in. Fig. 1 shows the method of making the bend on a standard tensile testing machine, also the method of determining the angle of bend. The total angle of bend is twice the angle formed between one leg of the specimen and the horizontal plane of the anvil. For the specimens single vee welds were made in 3/8-in. thick plate with low carbon steel rods

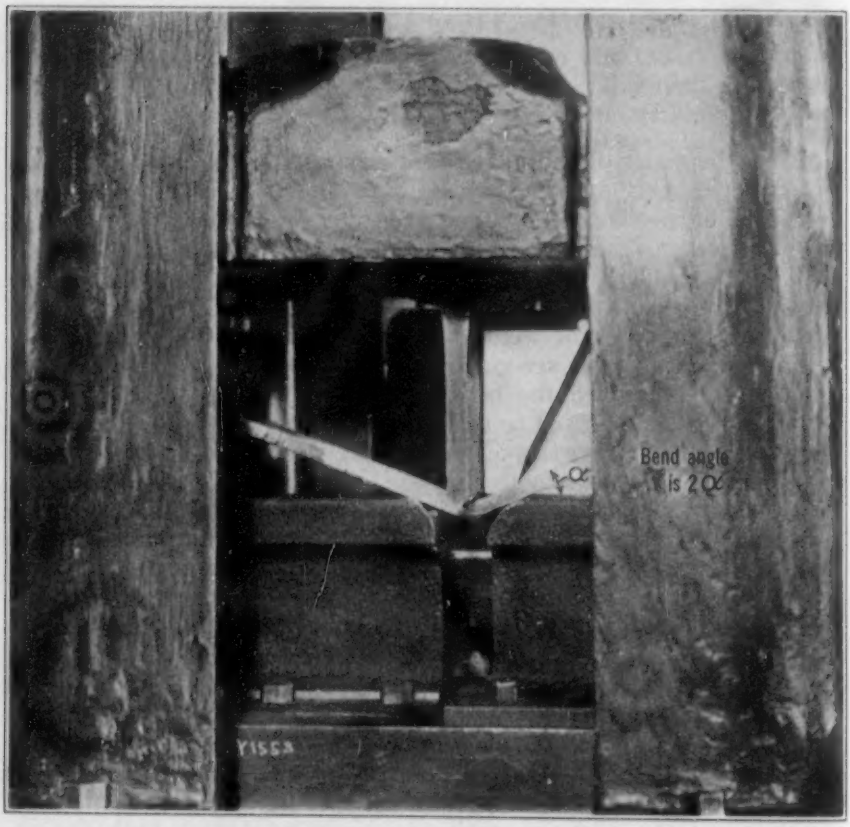

Fig. 1. Set up and method of measuring bend angle

and with rods giving considerably stronger welds. Coupons about 6 in. long and 1 in. wide were used. These dimensions check fairly well with Martens' recommendations that flats have a length of 18t and width of 3t. He also advocates a radius of 1/4t for sheared corners. We did not pay any attention to the curvature of the sheared corners. In Fig. 1 is shown the set-up and method of measuring the bend angle. The anvil opening was equal to the

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thickness of the ram plus twice the thickness of the specimen plus 1/8 in. The top of the machined single vee weld was placed down for we were more interested in the method than the weld tested. In the following table are the results obtained on the welds made

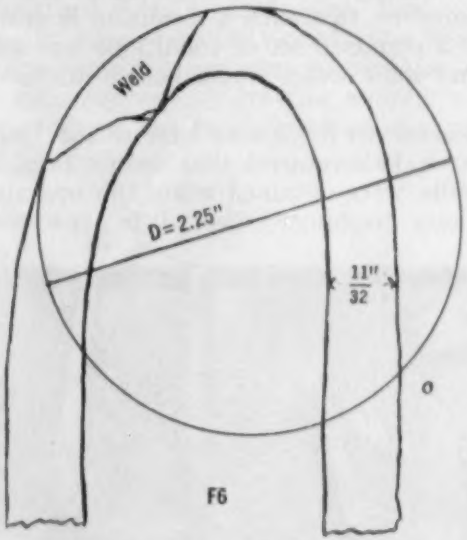

Fig. 2. Method of measuring bend angle

$$\% \text{ Elongation} = 100\frac{t}{2R}$$

t = thickness = .344
2R = D—t = 2.25—.344 = 1.906
Elongation calculated = 18%
Elongation measured = 17%

with two types of rod, using various ram sizes. In all instances the angle of first crack was the one measured.

One would naturally expect to obtain greater bend angles as the thickness of the ram was increased. However, a glance at Table I shows that this is not necessarily the case for with the high strength weld, lower bend angles were obtained with increasing ram size. The low carbon steel rod gave the best results with the

Table I

High Strength Weld			Low Strength Weld		
Specimen	Angle	Ram Thickness, In.	Specimen	Angle	Ram Thickness, In.
A	104	½	1	95	½
B	76	½	2	90	½
C	38	1	3	130	1
D	88	1	4	140	1
E	70	1	5	138	1
F	84	1	6	130	1
G	92	1	7	72	1½
H	74	1	8	82	½
I	58	1			
J	68	1½			
K	76	½			

The opening for K and No. 8 was set as for a 1-inch ram.

measuring the bend angle. The anvil opening was equal to the

1 in. ram. This would indicate that special size rams and possibly other conditions would have to be adopted for different type rods and welds. There is also an indication that under certain conditions the pressure of the ram on the concave side causes severe local stresses resulting in cracks forming at low bend angles. It is obvious, therefore, that such a condition is entirely unsatisfactory. Even if a standard set of conditions was adopted, the indications are that some welds would benefit while others would be penalized.

It has been observed for a long time in the Union Carbide and Carbon Research Laboratories that better bend tests and more consistent results were obtained when the operation was carried out in an ordinary machinist's vise. It is not uncommon to obtain

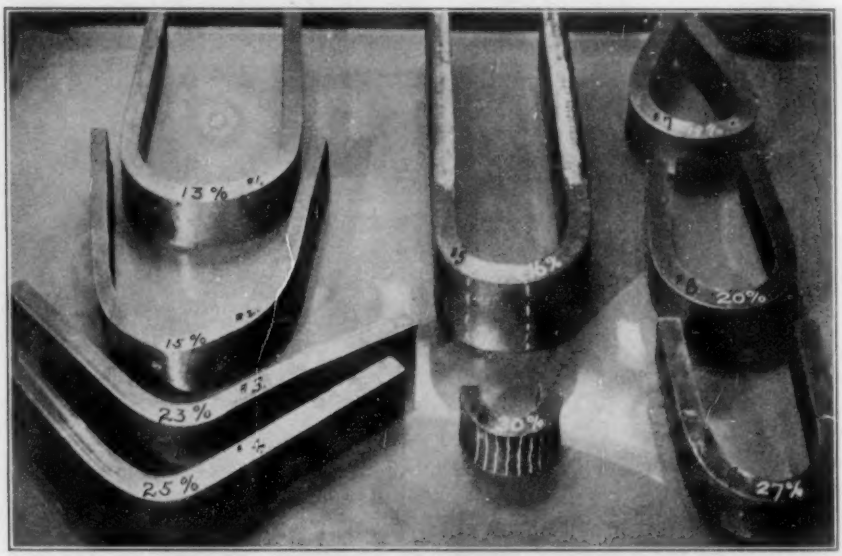

Fig. 3. Bends made in welded coupons

bend tests through an angle of 180 deg. with a relatively small radius of curvature. The slow bending in the vise without any external pressure applied to the concave side of the specimen seems conducive to more consistent results. Perhaps the absence of the pressure on the concave side of the specimen allows the metal to flow more freely on this side, thus avoiding severe local stresses which would otherwise cause premature failure.

Since the bend test is one of ductility, it occurred to us to measure it in terms of per cent elongation of outside fibers. For this purpose transverse lines 1/8 in. apart were drawn across the specimen in the weld area. By this means the per cent elongation of the outside fibers could be measured directly over any gage length up to 1 in. or more. According to Johnson's "Materials of Construction," if the neutral plane is considered to remain in the center

of the piece during bending, the per cent elongation in the outside fibers is $100 \frac{t}{2R}$, where t is the thickness of the specimen and R the radius of curvature of the neutral plane. However, no mention was made of directly measuring the elongation. We now have two methods of determining the per cent elongation of the outside fibers of a bend specimen, one by drawing a circle to coincide with the outside curvature of the bend specimen and calculating the

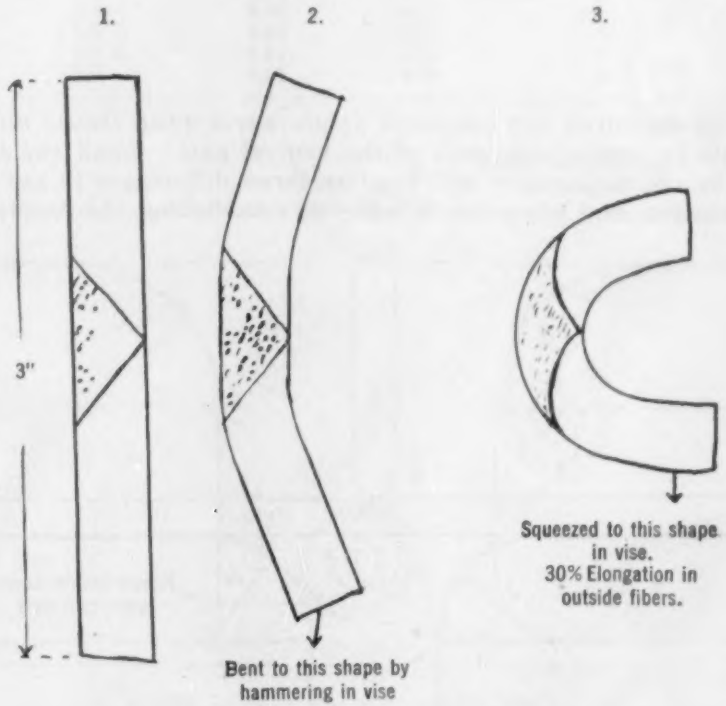

Fig. 4. Sequence of operations in bending short specimens

elongation according to the above formula, the other to establish gage marks before bending and actually measure the extension with a thin flexible scale.

Several bends were made on previously graduated specimens varying in width from 3t to 6t, some being made in a vise, and some on a standard bending machine in which the coupon is wiped around a pin. The pen cent elongation was measured directly over a gage length of 1 in. and was also calculated by the formula $100 \frac{t}{2R}$. The method of calculation is shown in Fig. 2. In practically all cases there was obtained about 20 per cent elongation. The circle was drawn to coincide with about 1 1/4 in. of the out-

side curve of the weld or the length attained by the original 1 in. gage length. Fig. 2 is an actual tracing of a bent coupon. In Table 2 is shown a comparison of measured and calculated values for per cent elongation over the weld area in eight bends.

Table II

Specimen No.	Per Cent Elongation Measured	Computed	Difference
1	17.0	18.0	+ 1.0
2	15.0	14.3	— 0.7
3	30.0	26.2	— 3.8
4	17.0	15.9	— 1.1
5	22.0	20.9	— 1.1
6	16.0	15.4	— 0.6
7	13.0	14.5	+ 1.5
8	40.0	39.3	— 0.7

The measured and computed values agree quite closely and indicate no appreciable shift of the neutral axis. Small variations in the circle diameter will produce large differences in per cent elongation, and when the difficulty of establishing the proper cir-

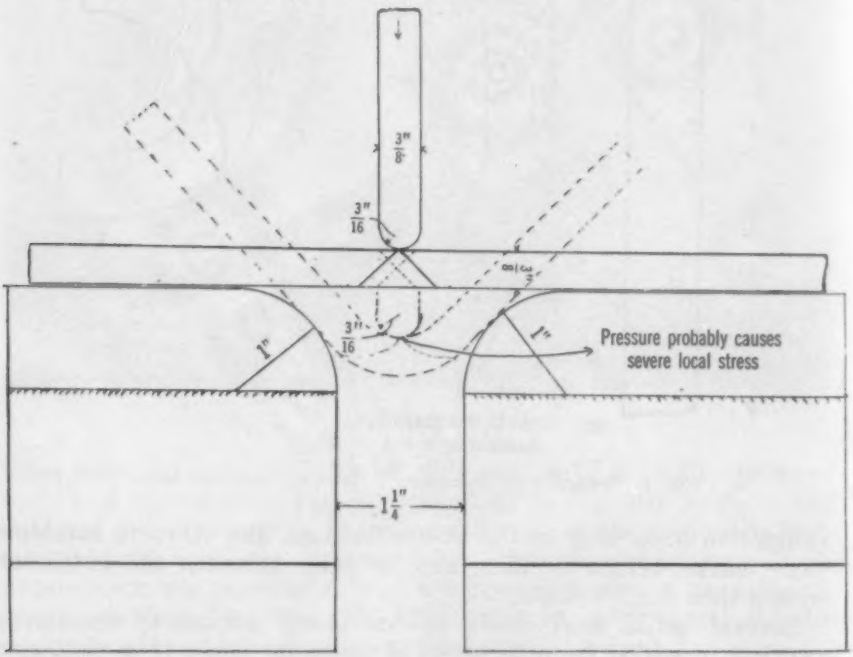

Fig. 5. Method of making bend test according to A. W. S. specifications

cle is considered, we feel that the direct measurement is more simple and reliable. In Fig. 3 are shown several bends on which the percent elongation was measured directly. If one were to judge the quality by the bend angles, it would be difficult to arrive at any satisfactory conclusion. By measuring the per cent elongation

The circle was drawn to coincide with about 1 1/4 in. of the out-

directly, definite numerical values were obtained of the bending quality of the materials. Nos. 1 and 2 bent in a vise, are from a weld with a tensile strength of over 90,000 lbs./sq. in. and show what quality may be expected from such high strength welds. Nos. 3 and 4 were made on the American Welding Society apparatus and show the elongation usually obtained on welds in 3/8 in. thick plate, made with low carbon steel rods. The bend No. 5 was made on a wide specimen, roughly 6t, in a commercial bending machine.

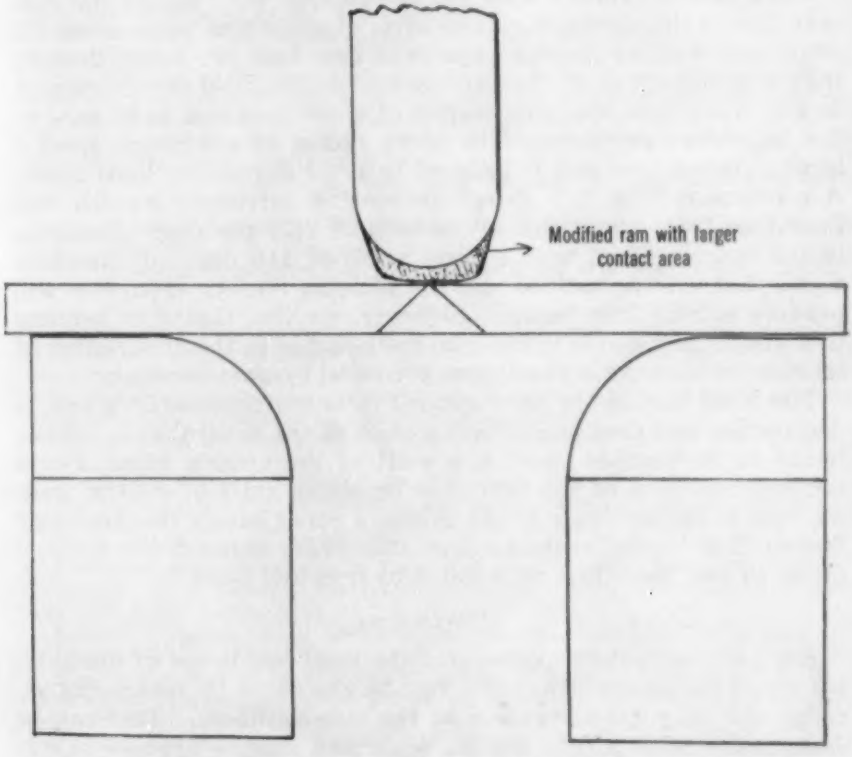

Fig. 6. Bend test with modified ram

It will be noticed that the weld did not come in the center of the bend, also that the bend is not of uniform curvature. It was noticed that bends so made usually took a minimum radius of bend when a 90 deg. angle was reached. Any further bending was at a larger radius of curvature. Nos. 7, 8 and 9 were made in an ordinary vise, the bend being initiated by hammering. In vise bending, it was found that, in thicknesses up to 3/8 in. satisfactory results could be obtained on 3 in. long specimens. The sequence of operations when bending short specimens is shown in Fig. 4. No. 6 in Fig. 3 is a 3 in. long specimen 3/8 in. thick and shows a uniform bend with excellent ductility. In making bend tests in a vise we find that good results may be obtained on any length specimen by

first initiating bend about 1/2 in. from each side of the weld by light hammering. The specimen is then inserted in the vise so as to bring pressure on the ends which causes the coupon to take on a uniform curvature as the vise is tightened. The specimen is suitably gage marked, preferably by small punch marks which do not initiate cracks, and the bending carried to the first sign of cracking, after which the elongation may be easily measured with a flexible scale.

Since it was believed that the pressure of the ram on the concave side of the specimen caused severe local stress when using the American Welding Society apparatus (see Fig. 5), it was thought that a modification of the ram design might yield better results. In Fig. 6 is shown the cross-section of a modified ram to be used on 3/8 in. thick specimens. The large radius of curvature gives a larger contact area and is believed to avoid any severe local stress. A bend made with this design showed an extremely smooth surface, free from any signs of cracking at 26.5 per cent elongation in the outside fibers with a bend angle of 110 deg. It therefore seems that with a modified ram the Welding Society apparatus will produce satisfactory bends. However, we feel that free bending in a vise is preferable to the ram method due to the elimination of tension stresses other than those produced by pure bending.

The bend test, as we have applied it, is not necessarily a test to destruction and does not involve a shift of the neutral axis. When tested to destruction there is a shift of the neutral axis. For a complete analysis of the bend test involving shift of neutral axis, we wish to call attention to Mr. Kinzel's paper before the American Society for Steel Treating, Sept. 23, 1927, entitled "A Critical Study of the Bend Test as Applied to Iron and Steel."

Conclusions

Since it is generally agreed that the bend test is one of ductility, we would recommend that this test be evaluated by measuring directly the per cent elongation of the outside fibers. This can be done easily with a thin flexible scale and can be applied to any specimen however bent. The measuring of a bend angle, especially on welded specimens, leads to false assumptions, for equal bend angles have been found to give quite a large difference in per cent elongation of the outside fibers. Any gage length may be used, but one which takes in a little more than the width of the weld would appear most logical. Bending in a vise removes any possibility of severe local stresses with possible premature failure, and may be successfully applied to specimens as short as 3 in. in thicknesses up to 3/8 in. or more. We feel that the measuring of the bend angle is fundamentally wrong and should be superseded by a measurement of per cent elongation, especially on welded coupons. This method of evaluating bend tests suggests the possibility of specifying that weld show a certain per cent elongation without failure or a definite minimum amount at failure.

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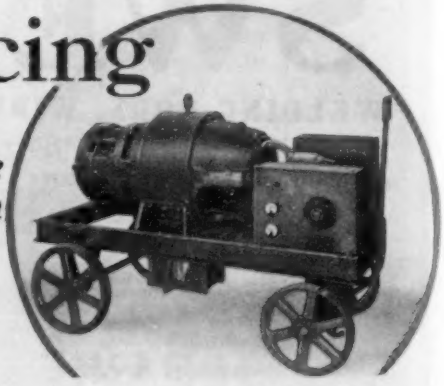

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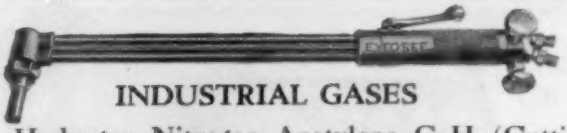

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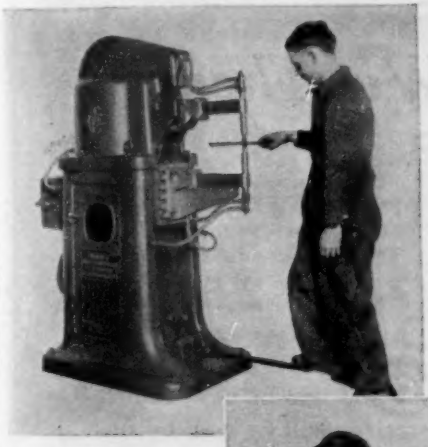

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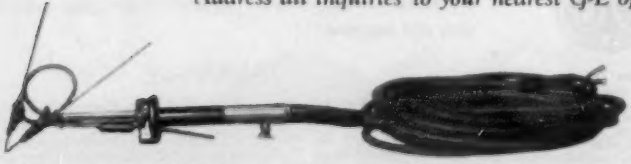

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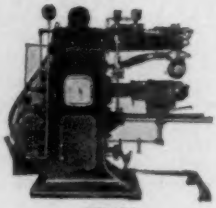

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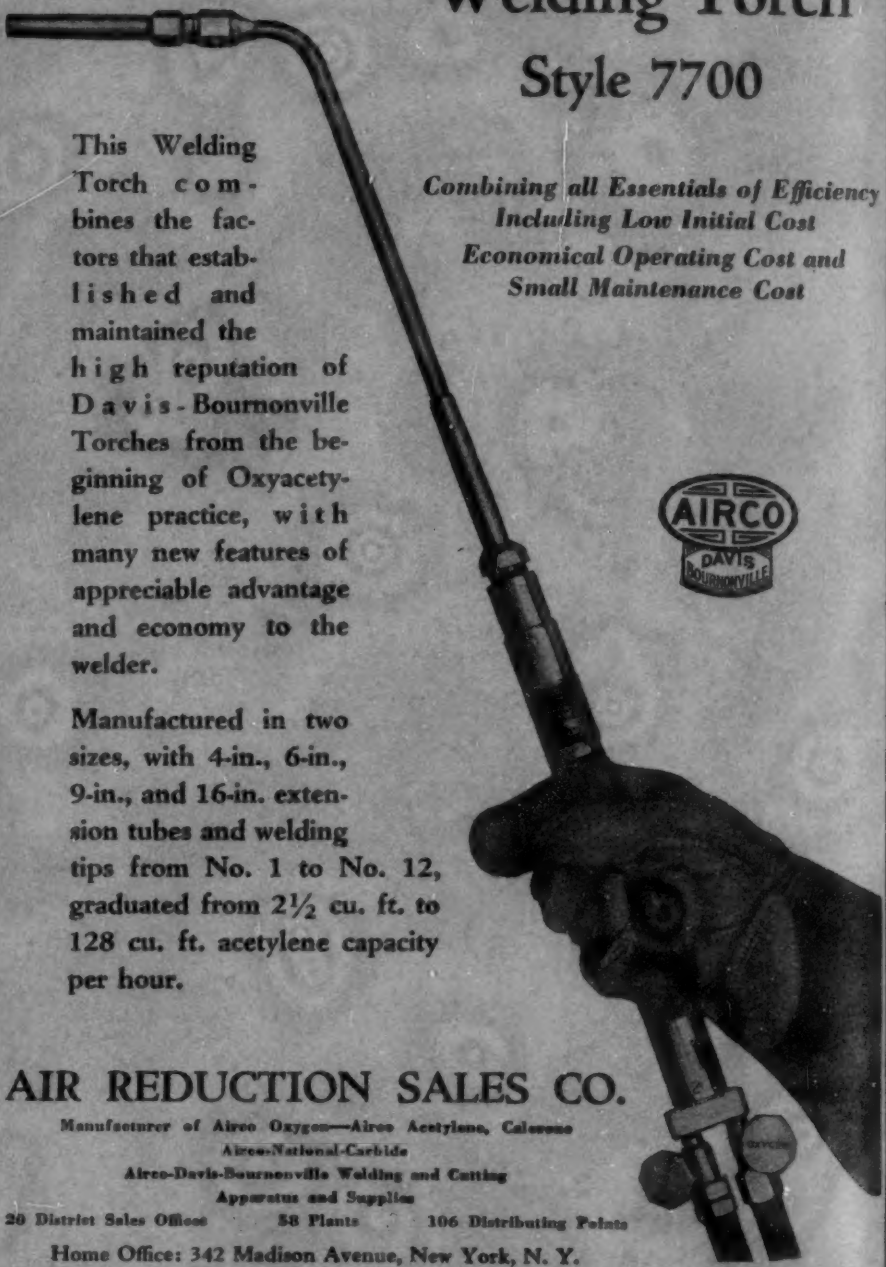

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